Publication No. 86-e07

WA-07-0010

ECOLOGICAL BASELINE AND MONITORING PROJECT

FINAL REPORT

PART 4: THE EFFECTS OF PULP MILL LOAD REDUCTIONS ON WATER QUALITY IN PORT GARDNER, WASHINGTON

by

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June 1986

PREFACE

The Ecological Baseline and Monitoring (ECOBAM) project was conducted in the Everett/Port Gardner area from 1972 through 1981. Most of the earlier work was published in the ECOBAM Summary Report (November 1976). Draft reports of the later work were prepared several years ago, but never finalized. Recent interest in the Port Gardner area has prompted finalization of this historical information.

Completion of the reports was not possible in all cases. Some of the researchers originally involved were no longer available and questions concerning methods, station locations, etc. could not be answered. However, four reports were completed and together they constitute the final report for the ECOBAM project. The four parts of the final report are:

Part 1: Livebox Bioassay Studies in Port Gardner, Washington by D. Clark

Part 2: Routine Water Quality Sampling and Intensive Surveys Data from Port Gardner, Washington, by T. Determan, W. Kendra, and D. Clark

Part 3: Distribution and Abundance of Benthic Macrofauna Adjacent to a Sulfite Pulp Mill Discharge Pipeline in Port Gardner, Washington, 1974 through 1976, by D. Kisker

Part 4: The Effects of Pulp Mill Load Reductions on Water Quality in Port Gardner, Washington, by T. Determan

ABSTRACT

Biochemical oxygen demand (BOD) from pulp industries on the Port Gardner waterfront was reduced by 97 percent between 1974 and 1981. Several water quality parameters improved in Port Gardner during this period. Trend analysis showed that spent sulfite liquor (SSL) significantly declined at all sampling sites. Dissolved oxygen (D.O.) increased at four of five sites in the East Waterway closest to shoreside sources. Correlation analysis revealed significant association of load reductions with decreased Pearl-Benson index (PBI) values. Although PBI, D.O., and pH were correlated, D.O. was not correlated with BOD due to other interacting factors.

INTRODUCTION

The Ecological Baseline and Monitoring Study (ECOBAM) was initiated in 1972. The objective was to monitor the effects on water quality of improvement in treatment and disposal of industrial effluent from two major pulp producers--the Weyerhaeuser Corporation, and Scott Paper Company. The Washington Department of Ecology (Ecology), University of Washington (UW), the Washington Department of Fisheries (WDF), Region X of the Environmental Protection Agency (EPA), and the two industries participated in the joint study. The role of Ecology was to:

1. Perform toxicity studies on juvenile salmon and oyster larvae.

2. Monitor the condition of bottom-dwelling animal communities.

3. Routinely collect data on water quality and fish population.

These studies were confined to the East Waterway (Everett Harbor) and Port Gardner shoreline to the southwest. The results of the juvenile salmon toxicity study are presented by Clark (1986). Reports on the other aspects of Tasks 1 and 2 will not be done because of poor data. This report addresses the third task. The data from routine sampling are reported by Determan, et al. (1986).

ECOBAM routine field data were collected from May 1974 through March 1981. During the study, a number of changes occurred in both field and laboratory procedures and staff. Although every effort was made to ensure that the sampling program was maintained as envisioned by its original designers, it was inevitable that subtle variations in procedures occurred. These variations were given consideration in the preparation of this report. I cannot claim credit for the initial study design; however, I accept responsibility for the data interpretation and conclusions.

The initial design for ECOBAM focused on conventional parameters. Recently the toxic effects of metals and specific organic compounds on marine organisms has raised considerable interest, but were beyond the scope and technology of the time.

BACKGROUND

Environmental Setting

Past studies have shown the effects of waste loads from the Everett area on waters far removed from the location of discharges. It is therefore appropriate to review the oceanographic processes affecting water circulation and the distribution of materials in the region.

The Whidbey Basin is composed of three major compartments: Possession Sound, Port Susan, and Saratoga Passage (Figure 1). Saratoga Passage extends 50 kilometers northeast of Gedney Island to Deception Pass. Possession Sound and Saratoga Passage form a continuous subbasin. Depths along the axis range from 220 meters at the Whidbey Basin entrance to 25 to 30 meters in Skagit Bay. Port Susan is separated from Saratoga Passage by Camano Island. The maximum depth at the south end of Port Susan is about 110 meters. The Stillaguamish River delta and associated tideflats cover a third of northern Port Susan. The Snohomish River delta near Everett forms extensive mudflats in the southern basin.

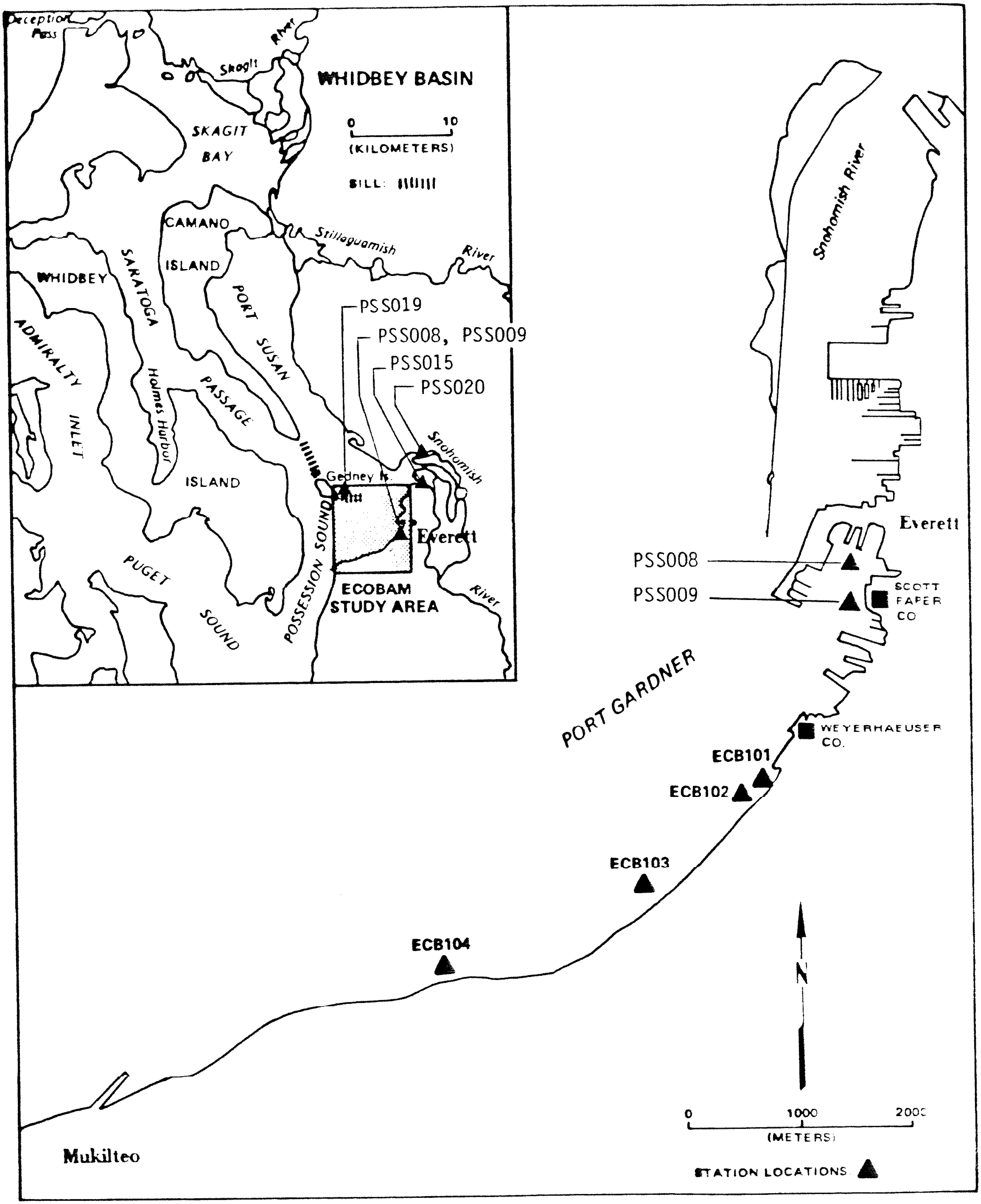

Figure 1. Port Gardner and Possession Sound showing the locations of beach stations used during ECOBAM sampling and nearby Ecology ambient monitoring sites (adapted from NOAA chart 18444).

The tides in Puget Sound are semi-diurnal. Two highs and two lows occur each tidal day of 24 hours 50 minutes (Lincoln, 1979). The tidal range varies markedly, especially for the lower tides. The mean range is 3.4 meters.

Numerous rivers and streams flow into the Whidbey Basin. These sources contribute nearly 70 percent of the freshwater discharged into Puget Sound from all sources combined, including Hood Canal and Southern Puget Sound. The large discharge of freshwater from the Skagit, Stillaguamish, and Snohomish Rivers is the reason that the Whidbey Basin has an estimated annual average flushing time of 49 days, the shortest among all the Puget Sound subbasins (Friebertshauser and Duxbury, 1972). There are two distinct periods of high river flow. A mid-winter maximum occurs due to direct runoff. Snowmelt from the Cascades accounts for a second peak in early summer. Minimal flow occurs in mid-spring and fall.

Water circulation in estuaries and inlets theoretically is dominated generally by the interaction of two driving forces. The first, an estuarine flow, is brought about by the mixture of outflowing freshwater runoff from rivers and streams with the denser saltwater underlying it. Seawater flows into the estuary at depth to replace the mixed flow moving outward at the surface.

This "density-driven" circulation is modified by the second driving force--the tide. Tides act to quicken the mixing process within the estuary and to reduce the degree of vertical stratification (Collias, et al., 1974). The Puget Sound physical model at the Department of Oceanography, UW, was used to study the vertical distribution of current in Possession Sound (U.S. Dept. of Interior, 1967). The study showed the surface layer and the underlying mid-depth waters follow the theoretical pattern described above. However, a near-bottom layer was found had a net movement outward into the main Puget Sound basin.

A submerged sill extends from Camano Head through Gedney Island and easterly toward Everett. The sill averages 25 meters in depth and limits the exchange of Port Susan deep waters with Possession Sound and Saratoga Passage. No sill separates the deep waters of Possession Sound/Saratoga Passage from the Puget Sound main basin (Friebertshauser and Duxbury, 1972).

In Port Susan, the shallow waters above sill depth (25 meters) respond to the same tidally modified, density-driven circulation as the rest of Whidbey Basin. But the denser waters below sill depth are exchanged only annually by the cool, saline waters that enter Puget Sound on the bottom from coastal upwelling. This water flows over the sill and displaces the bottom water in Port Susan in late summer or early fall and remains there until replaced (Barnes and Collias, 1958). During the ensuing year, the deposition of organic material and subsequent decomposition at depth cause an oxygen reduction in the stagnant bottom waters. Barnes and Collias (1958) estimated the rate of oxygen utilization in Port Susan to average 0.024 mg/L/day at 120 m, which is similar to the value they calculated from 150 observations Puget-Sound wide. On the basis of this value, and in the absence of downward diffusion, water remaining at basin depth for about one year would be depleted of oxygen. Because of this, deep water behind the sill may be sensitive to accelerated organic loading.

Port Gardner lies on the east side of Possession Sound. The East Waterway (Everett Harbor) is quite shallow--10 meters at mean lower low water (MLLW). The bottom is featureless with little overall gradient. About 400 meters southwest of the mouth of the waterway, the bottom drops steeply to an average depth of 100 meters (CH_2M Hill, 1974).

The water circulation within Port Gardner and the East Waterway has been studied by several authors (Bartsch, et al., 1967; USDI, 1967; CH_2M Hill, 1974). The tidal component tends to be weak and variable. The Snohomish River greatly dilutes surface waters. As a result, a low-density surface layer about five meters deep creates a stratified, partially mixed, two-layer estuarine system.

CH_2M Hill (1974) used the tidal prism method (Bowden, 1967) to calculate a theoretical flushing time for the East Waterway of approximately 54 hours. Bottom waters move in during flood tide and out during ebb. Surface waters respond in the opposite manner, although short-term oscillations and eddies have been noted. Net movement of surface waters is southwesterly parallel to shore toward Mukilteo. CH_2M Hill (1974) followed dye tracer five kilometers southwest of the Scott Paper Company plant. Another dye patch was found 1,200 meters upstream in the Snohomish River.

Process wastes from the Weyerhaeuser Company and the Scott Paper Company have undergone changes in quality, quantity, and discharge locations during many years of operation. In 1951 both industries discharged large fractions of their waste through a common deep-water pipeline with a diffuser (Orlob, et al., 1951). The multiple-port diffuser is 300 meters long and is located 900 meters offshore in about 100 meters of water (USDI, 1967).

Both industries also discharged into nearshore waters. Details on present locations and changes in discharge locations during the years of study are given in Table 1 and Figure 2. Weyerhaeuser (1981) discusses changes in waste loads, treatment processes, and production.

Effluent dilution and dispersion is governed by the stratification regimes at the point of discharge. Low-density effluents discharged from the deep diffuser rise and mix until the density of the plume equals that of the surrounding water. The depth of this "trapping layer" has been estimated to be from as shallow as 15 m (Bartsch, et al., 1967) to as deep as 75 m (USDI, 1967). The plume was tracked northward for 6 to 8 kilometers. Effluent entrained at mid-depth moved northward toward Saratoga Passage and Port Susan. Effluent entrained in bottom waters moved south into Possession Sound. Mid-depth effluents may enter Port Susan, sink, and remain behind the sill until annual replacement occurs.

Table 1. Descriptions of industrial outfalls in the Everett East Waterway and vicinity (from Clark, 1986).

Description of Outfalls	Comments
Outfall 001 - Deepwater diffuser located 500 yards due west of the Weyerhaeuser pulp mill.	The waste stream included a portion of the treated process water from the Scott first clarifier and wastewater from the Weyerhaeuser mill. Mill ceased operation in December 1980.
Outfall 004 - Small embayment located between Scott Ppaer Company's original facilities and the tissue plant.	Discontinued in April 1981. The discharge was from the Scott Paper tissue bleach plant. The process water is now routed to the first clarifier and discharged at 003 after treatment. Used for discharging a waste stream containing chlorine. Bay partially filled in 1978. Discharge ended April 1981.
Outfall 003 - Diffuser located along the southern two-thirds of the Scott Paper Company pier.	Treated wastewater from the first primary clarifier is discharged through the diffuser after passing through a weir that splits the stream, sending part of it through the diffuser and the remainder to deepwater diffuser 001. The clarifier removes suspended solids from the stream which is then treated with caustic soda to raise the pH level prior to discharge to the inner harbor. Stormwater also is discharged at 003 by way of the Benson sewer that connects to waste stream prior to discharge.
Outfall 008 - Diffuser for the Scott treatment plant located at the northern terminus of the waterway.	Put on line in the spring of 1980. Spent sulfite liquor is treated in the plant using the activated sludge process and areation basins prior to discharge.
Silt Trap - North end of East Waterway.	The new City of Everett discharge is associated with a major tideland-fill project located north of the East Waterway. Water draining from the fill area is directed to a silt trap and then discharged into the northern end of the waterway.

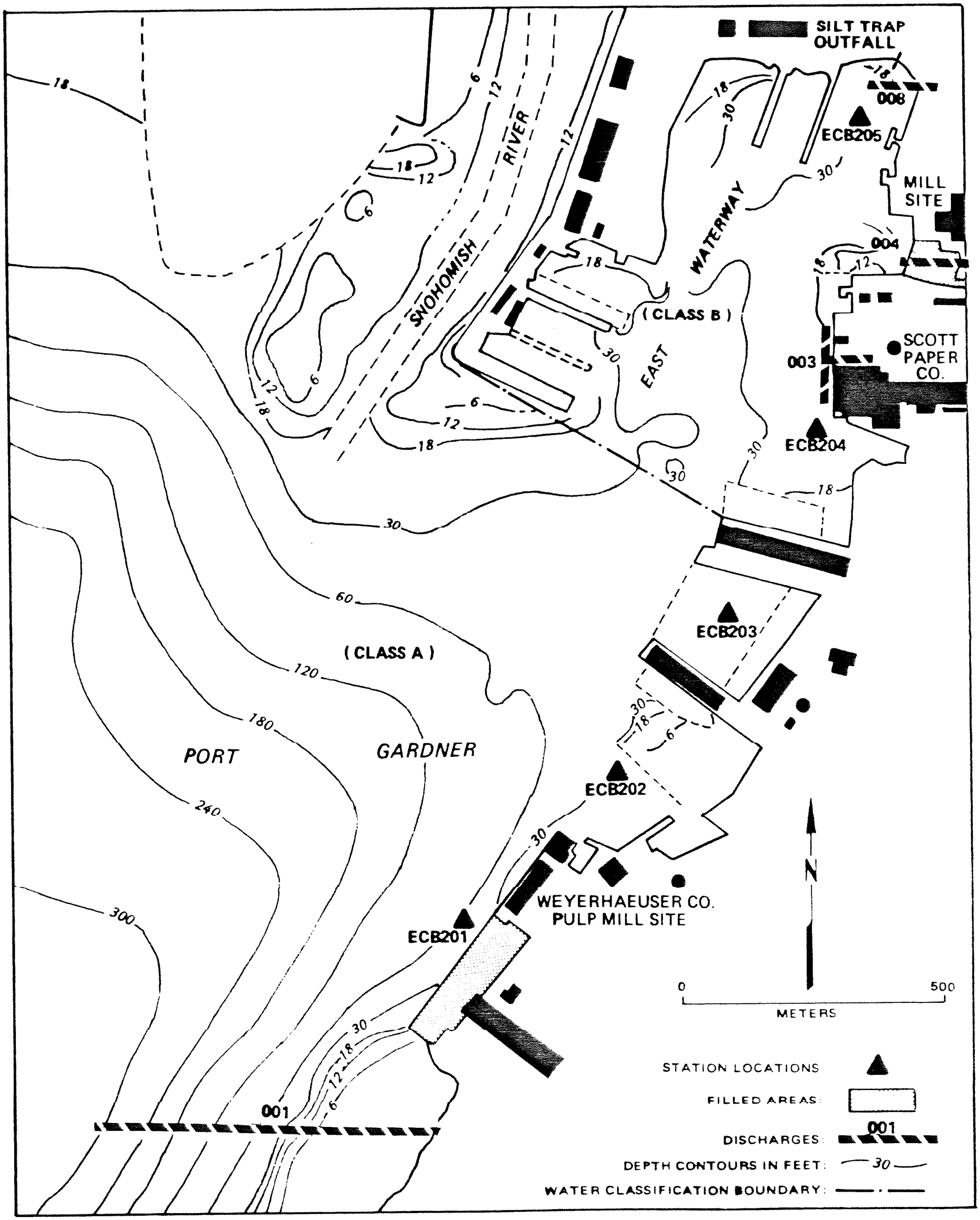

Figure 2. Everett East Waterway showing the locations of ECOBAM deep stations and present and past discharges (adapted from NOAA chart 18083).

Nearshore effluents released into the shallow East Waterway are confined to the low-density surface layer (Bartsch, et al., 1967; CH_2M Hill, 1974). Lasater (1954) determined that pollutants in surface waters tended to remain in the waterway. Surface movement from Port Gardner is almost entirely southward through Possession Sound. This fact was also observed by USDI (1967).

In addition to the two East Waterway pulping industries, Port Gardner surface waters receive diverse point- and non-point pollution. This probably has the greatest impact at the surface. There are municipal and light industrial wastes, leachates (tannins and lignins) from extensive log rafting, and wastewaters from other wood products companies (Cardwell, et al., 1977).

The role of domestic wastes on the quality of Port Gardner waters was evaluated by Cheyne and Foster (1942) in response to a complaint filed by the Snohomish County Sportmans' Association in 1937. A number of raw sewers and combined storm water discharges were located on the East Waterway shoreline and along the Snohomish Rover. BOD contributions due to sewage accounted for three percent, while BOD from pulp mill wastes made up 97 percent of the total. Everett's domestic wastes, storm water, and some industrial wastes are now diverted to the Everett sewage treatment plant (STP) located 5 river-miles upstream from the mouth of the Snohomish River. The closure of the Simpson kraft mill on the Snohomish River and implementation of secondary treatment of municipal wastes have reduced the BOD loads by 50 percent (Cardwell, et al., 1977). Singleton, et al. (1982) estimated the six-month average BOD load from Everett STP to be 1.2 tons/day.

The Weyerhaeuser Corporation Kraft mill is located on the Snohomish River. However, efflient is treated on Smith Island and discharged into Steamboat Slough (north of Smith Island) on a dropping tide to minimize direct discharge into the Snohomish River system. The current NPDES permit limits the BOD load to 3.3 tons per day. Recent data indicate the discharge is well within the limit (Bruce Johnson, Ecology Industrial Section, personal communication).

Characteristics of Pulp Mill Effluents

The Scott Paper Company plant is an ammonia-base pulp and paper mill. In 1975, Weyerhaeuser Company converted their calcium-base sulfite mill (Cardwell, _et al_., 1977) to a thermal-mechanical process which eliminated SSL from the discharge. This plant closed in December 1980.

SSL has three recognized waste fractions (Cheyne and Foster, 1942):

1. Solutions of sulfites, bi-sulfites, and sulfur dioxide as calcium or ammonium salts.

2. Solutions of sugars and sugar derivatives, such as pentose, hexose, aldehyde, and alcohol.

3. Solutions of calcium or ammonium lignin sulfonate.

The decomposition of organic materials contained in SSL exert a demand for oxygen. Early bioassays concluded that lowered D.O. was the major component in fatalities of fish in the East Waterway (Cheyne and Foster, 1942; Townsend, _et al_., 1941). But fatalities of salmon during tests at high SSL concentrations suggested a toxic component separate from oxygen effects (Williams, _et al_., 1953).

Holland, et al. (1960) determined the "critical level" of effluent components (other than SSL) in both Kraft and sulfite wastes for young salmon for a variety of lengths and exposure times. They defined the "critical level" of effluent to be that which produced effects ranging from a minimum of no deaths to a maximum of obvious distress symptoms or reduction in growth rates. The critical level of chlorinated viscose wash water was 33% for 9mm Silver salmon fry exposed 3 days in aerated fresh water. The critical level of caustic viscose wash for similar fish under identical test conditions was 50%. The critical level was 3% for 10mm Pink salmon exposed to combined chlorinated and caustic viscose wash in aerated salt water for 30 days.

Nearly 300 compounds have been reported in the literature as constituents of pulp mill effluent (Nestmann, et al., 1980). Many of these compounds are generated by chlorination of effluent containing lignin or other byproducts of the physical and chemical degradation of wood fibers.

Specific compounds present in an effluent are functions of wood species, pulping process, the presence or absence of bleaching, and the degree and type of treatment (Yake, 1982). Some compounds are acutely toxic. Other compounds produce sublethal and mutagenic effects, such as failure of shell development in oyster larvae (Kringstad, et al., 1981).

Spent Sulfite Liquor (SSL) and the Pearl-Benson Index (PBI)

SSL was selected as an important variable in ECOBAM because it is associated with pulp plant discharges. The use of SSL has been controversial, however.

The concentration of SSL in marine and freshwaters is estimated by the Pearl-Benson Index (PBI). Numerous studies have employed PBI as a fundamental variable to trace the movement of SSL in marine waters of Puget Sound (Townsend, et al., 1941; Eldridge and Orlob, 1951; Orlob, et al., 1951; Lasater, 1954; USDI, 1967; Bartsch, et al., 1967), Bellingham Bay (Bartsch, et al., 1967, USDI, 1967; Collias, et al., 1966), Strait of Juan de Fuca (Bartsch, et al., 1967; USDI, 1967), and British Columbia (Waldichuk, 1958). PBI also has been used in several laboratory bioassays (Williams, et al., 1953; Holland, et al., 1960).

SSL usually contains 10 to 13 percent total solids, and about 60 to 65 percent of these consist of lignin sulfonates, a phenolic-type substance (Felicetta and McCarthy, 1963). However, other naturally occuring phenolics (kraft lignins, tannins from bark extractives, and amines) and some inorganic substances are present. Besides background interference, the character of each discharge varies in types of lignin sulfonates and ratios of lignin sulfonates to total solids.

METHODS

Data Collection

Physical and chemical water quality data were recorded and surface grab samples taken. Field measurements were made for salinity, temperature, and Secchi depth readings. From 1976, Secchi depth was recorded (at deep seine stations only). Surface grab samples for pH and turbidity were taken in 250 mL polyethylene bottles, placed on ice, and returned to the Olympia Environmental Laboratory for analysis. Dissolved oxygen samples were taken with a stainless steel BOD bottle holder. Analysis using the Winkler (azide-modification) method was performed in the laboratory. A detailed discussion of all parameters, methods of analyses, and rationale for their use is found in Table 2. Table 2 also describes water quality standards for Port Gardner (Class A) and East Waterway (Class B). See Figure 2 for the legal boundary. The classifications are designated by Ecology (1980).

SSL samples were taken at the surface and placed on ice. During the course of the study, special precautions were taken to minimize the biodegradation of SSL Since the effects of temperature are important (Westley, 1960b), all samples were placed on ice immediately after sampling. Transportation time to the Ecology environmental laboratory was usually 24 to 36 hours. Maximum holding time in the laboratory was seven days (Freeman, Ecology Environmental Laboratory Supervisor, personal communication, 1982). During the holding period, temperatures were maintained at 4°C to minimize bacteriological activity.

Seining was performed at nine stations. Four stations (ECB101 through ECB 104) were evenly spaced along 4 kilometers of beach southwest of Everett (Figure 1). These stations were used to evaluate water quality changes "downstream" of the waterway. Five additional stations (ECB201 through ECB205) were located within the East Waterway (Figure 2). All nine stations were usually sampled monthly.

A beach seine measuring 30 meters long by 1.8 meters deep with a 0.13 cm^2 mesh size was used at stations ECB101 through ECB104. The net was stretched perpendicular to the beach and moved parallel to shore for 30 meters and then

Table 2. Parametric coverage and rationale for measuring each variable during ECOBAM Water Quality study in Port Gardner.

Parameter	Location	Method	Reason for Sampling	Water Quality Standard (Class A)	Water Quality Standard (Class B)
pH (S.U.)	All stations	Reference electrode pH meter	pH affects the carbonic acid-carbon dioxide balance in sea-water. pH also affects the activity of un-ionized ammonia and sulfide. EPA (1976) recommends pH values be within 6.5 to 9.0 pH units.	Within range of 7.0 to 8.5 with man-caused variations within a range of 0.5 unit.	Shall be within the range of 7.0 to 8.5 with a man-caused variation within a range of less than 0.5 unit.
Spent Sulfite Liquor (SSL) (mg/l)	All stations	Pearl-Benson Index (PBI): Perkin Elmer 360 Atomic Absorbtion spectro-photometer	SSL is a byproduct of the manufacture of paper from wood by the sulfite process. It also has a high oxygen demand (BOD) requirement when introduced into a receiving water. This results in a depletion of available oxygen for organisms in the system.	Toxic, radioactive, or deletrious material concentrations shall be below those of public health significance, or which may cause acute or chronic toxic conditions to the aquatic biota, or which may adversely affect any water use.	Toxic, radioactive, or deletrious material concentrations shall be below those which adversely affect public health during characteristic uses, or which may cause acute or chronic toxic conditions to the aquatic biota, or which may adversely affect the characteristic water uses.
Dissolved O_2 (% saturation)	All stations	Winkler - azide modification (APHA, 1976; EPA, 1979).	Elevated, relatively constant oxygen levels are essential for stable marine communities. Highly variable or consistently depressed levels downstream from a source may be indicative of an organic load in excess of the ability of the system to assimilate it.	Shall exceed 6.0 mg/L, except where upwelling occurs; natural D.O. may be degraded by up to 0.2 mg/L by man-caused activities.	Shall exceed 5.0 mg/L or 70% saturation whichever is greater, except when the natural phenomenon of upwelling occurs. Natural D.O. levels can be degraded by up to 0.2 mg/L by man-caused activities.
Temperature (°C)	All stations	Temperature function on Kahlisco model RS5-3 induction salinometer	Used with salinity to determine water density; temperature also affects D.O. solubility and rates of biological processes.	Not to exceed 16°C due to human activities. (t = 12/[T-2]) Note: "T" represents the highest existing temperature in these water classifications outside of any dilution zone.	Not to exceed 19°C due to human activities. (t = 16/T)
Turbidity (NTU) Total Susp. Solids (TSS, mg/L)	All stations	Turbidity: Hach Turbidimeter; TSS: APHA (1975), EPA (1979)	Measures water column transparency, light availability, and is an estimate of suspended material in water column. Sufficient light is essential to marine plant growth. Excessive suspended material may stress bottom-dwelling plants and animals by interference in filter feeding, and by light reduction, or smothering. Turbidity is a function of quantity and light scattering characteristics of the suspended material.	Not to exceed 5 NTU over background if background is 50 NTU or less or have more than a 20% increase in turbidity when the background turbidity is more than 50 NTU.	Not to exceed 10 NTU over background if background is 50 NTU or less or have more than a 20% increase in turbidity when the background turbidity is more than 50 NTU.
Secchi Depth (m)	All stations	Secchi disc lowered to depth of disappearance	Refer to Turbidity comments above.	No standard.	No standard.
Salinity (o/oo)	All stations	Kahlisco Model RS5-3 induction salinometer	Used to trace passage of fresh-water through marine waters; affects mixing rates, and density distribution in water column and solubility of dissolved oxygen.	In brackish waters of estuaries, where the fresh and marine water quality criteria differ within the same classification, the criteria shall be interpolated on the basis of salinity, except that the marine water quality criteria shall apply for dissolved oxygen when the salinity is one part per thousand or greater and for fecal coliform organisms when the salinity is ten parts per thousand or greater.	

brought up on the beach. Trapped fish and benthic organisms were counted by species, measured, and released. Two hauls were made at each station. Most beach seining was done during low tide when the water reached a depth of 0.6 meters above MLLW to take advantage of the flat, sandy subtidal zone in this area. Most of the year, seining was performed during daylight hours except in November and December when suitable tides occurred only after sunset.

A deep seine was used in the East Waterway (stations ECB201 through ECB205) because of lack of a beach. The net measured 84 meters long and tapered from 1.8 meters deep at the ends to 3.6 meters at the center purse. Mesh size ranged from 2.25 cm^2 at the end panels to 0.04 cm^2 in the purse. The buoyed end of the seine was dropped off the bow of the boat as it was backed in a circle. The buoy end was recovered after the purse was closed and both ends of the seine hauled aboard. Captured fish were counted, measured, and released. Usually, numerous ctenophores (comb jellies) were captured as well, but these were not included in the data. In all cases, deep seining was performed during daylight hours. Two hauls were made at each station. Deep seining was usually done during tides above mean high level.

Shannon diversity indices for each station were calculated using a program called INDICIES (Kruger, 1979). The Shannon diversity index is an estimate of uncertainty or disorder in a large, random collection of species taken from a very large population (Averett, 1974). The number of species present and the number of individuals within each species are determined from each collection. Essentially, the richness or variety of the community structure is noted and the question asked, "What is the likelihood that we can correctly predict the species of the next individual in the sample?" The greater the number of species available, the less likely we can predict which species the next individual will represent and, therefore, the greater the disorder or uncertainty. This is expressed mathematically as follows (Pielou, 1977).

$$H' = -\sum_{i=1}^{S} \frac{Ni}{N} \log_2 \frac{Ni}{N}$$

where: H' = species diversity of the sample
S = number of species in the sample
Ni = number of organisms of the ith species
N = number of all species

In a sample in which all organisms are of the same species, the uncertainty and, therefore, the diversity would be zero.

There were some problems with using the Shannon index for characterizing species diversity at the deep seine stations. During the course of the study, a number of deep seine hauls failed to catch any fish. No-catch hauls ranged from 21 percent of the total at station 205 to nearly 50 percent at station 201. Fish populations tend to be clumped in space and time. In addition, larger fish are able to avoid being caught. Deployment and recovery of the seine took about ten minutes and created considerable disturbance. Catches from the second haul usually were less than the first. This was also generally true for the beach stations. Thus, the first sampling affected the outcome of the second. For this reason, fish counts from duplicate hauls were pooled for both beach and deep seine sites.

In those cases where no fish were caught, a diversity index was not calculated because when $Ni = N = 0$, the above equation is rendered indeterminate. These occasions were therefore excluded from the computer analyses.

Receiving water data collected on any particular day of the month were assumed to change too quickly to test for association with monthly mean discharge values. Therefore, data were requested from industrial sources for the specific dates of sampling in order to "fine-tune" later statistical analyses. Daily BOD load data were provided by Weyerhaeuser Company. Daily load data from the Scott Paper Company were extracted from company records for the specific dates (by the author). BOD loads from Scott discharges were estimated from TSS by regression analysis. Total load from the deepwater diffuser was determined by adding the Weyerhaeuser Company and Scott Paper Company components. All nearshore discharges were combined into a single quantity.

Samples for SSL were analyzed for the Pearl-Benson Index (PBI). The PBI test was developed under the auspices of the pulp and paper industry. Lack of standard procedures led to confusion over interpretation of results. An effort to standardize the procedure was later undertaken (Felicetta and McCarthy, 1963; Barnes, et al., 1963). The PBI, or Nitroso, method is based upon the reaction with a range of simple to complex phenolic compounds in SSL to produce colored substances. The density of the color is proportional to the concentration of phenolic substances.

Barnes, et al. (1963) developed a primary standard consisting of an arbitrarily selected calcium-base SSL which was dried and packaged for sale to laboratories. The Ecology Environmental Laboratory (Olympia) used this standard SSL calibration method until 1974 when the supply of "Standard Ca SSL Solids" was exhausted. Since that time, PBI values have been estimated using a regression equation developed while the standard was available (J. Freeman, Ecology, Environmental Laboratory Supervisor, 1982, personal communication).

A background PBI value for this study was estimated from data obtained during a strike-related shutdown of the pulp mills. Both mills were closed from October 1978 through January 1979. During this period, the average PBI at the five East Waterway stations was 3.9 ± 2.9 (20 samples) ppm. The beach stations to the south averaged 5.5 ± 3.1 (12 samples) ppm. These values suggest that a background of about 5.0 ppm is reasonable. This value also is near the minimum sensitivity limit of the anations was 3.9 ± 2.9 (20 samples) ppm. The beach stations to the south averaged 5.5 ± 3.1 (12 samples) ppm. These values suggest that a background of about 5.0 ppm is reasonable. This value also is near the minimum sensitivity limit of the analytical method (S.Robb, Chemist, Ecology Environmental Laboratory, personal communication, 1982).

Barnes, et al. (1963) report background values of 2 to 3 ppm apparent SSL in seawater samples taken 32 kilometers off the coast of Washington. Bartsch, et al. (1967) reported 2 ppm or less in the Strait of Juan de Fuca and 5 ppm in Samish Bay. Waldichuk (1958) considered PBI values less than 10 ppm in a British Columbia inlet to be insignificant. Westley (1960a) reported maximum PBI values of 2.0 ppm from Willapa Bay; and 2.0 ppm at Point Whitney, Hood Canal.

Westley (1960b) addressed degradation of SSL over time under laboratory and field conditions. In laboratory tests, calcium-based samples were kept in one-liter glass bottles at 20°C. The rate of degradation was about one percent per day when the initial concentration was 75 ppm PBI. Greater concentrations degraded more slowly.

Westley (1960b) also conducted experiments in a semi-enclosed lagoon to measure the decline of SSL under environmental conditions. Warm-weather rates were nearly twice that of cold weather. The half-life of SSL was about one week or about 12 percent per day at 20°C.

The D.O. saturation was determined using DOSAT (Kruger, 1979) on a Wang 2200 VP computer. All data for each station were stored in STORET, a data storage system managed by U.S. EPA, in a parameter versus date matrix format. Data from each sampling site were plotted against time using GUS (Wang's Graphic Utility System). Each graph shows a linear regression line calculated and plotted by the system. A trend analysis was performed using Spearman's Rho, a non-parametric statistical test for rank correlation between each variable with time. It was calculated using TREND by EPA Region X. The program tests the significance of trends and includes deseasonalization procedure for dissolved oxygen and temperature. The non-parametric Kendall's Tau test was used to detect the presence and strength (rank) of correlations between water quality parameters. In this way, those parameters that either varied together or were mutually affectd by loadings could be identified, and possible cause-and-effect relationships hypothesized. Kendall's Tau was calculated using a BMDP-79 statistical package (Dixon and Brown, 1979). Both the trends and correlations were performed by Ray Peterson, EPA Region X.

The BMDP program limits the number of parameters to ten. For this reason, the parameters chosen were those deemed in advance to be most related to the discharges. Salinity was not included initially. Later, the data suggested a possible relationship between salinity and pH. In this case, product-moment correlation coefficients were calculated (for this pair only) using a Hewlett-Packard Model 25 programmable calculator.

Two facts should be borne in mind when considering the results of the correlation analysis. First, the test detects the significance of correlation as well as the degree of correlation. Relatively low values suggest that although there is "significant" correlation between two variables, an unknown number of factors interact to weaken the association. High variability in the data may be produced by seasonal, tidal, physical, or chemical effects. Effects of other wood processing and handling activities and natural processes in Port Gardner and the lower Snohomish River may play a role.

Second, one can demonstrate association or correlation between two variables without proving cause and effect. Processes that change with time may be correlated simply because the change with time happens to be in the same direction (Sokal and Rohlf, 1969).

RESULTS AND DISCUSSION

BOD loads from each plant were reduced substantially from 1974 to 1981 (Figure 3, Table 3). The total load declined to less than three percent of initial values. Loads from the deepwater diffuser were reduced the greatest degree (more than 99 percent), while nearshore reduction was somewhat less (23 percent of initial value).

From May 1974 to April 1975, the offshore load was somewhat evenly shared by both Weyerhaeuser Company and Scott Paper Company. A sharp drop in offshore load occurred in mid-1975 when Weyerhaeuser shut down its mill to convert to a thermomechanical process. During this time, nearshore loads (attributable solely to Scott Company) remained relatively constant at about 12 percent of the offshore load. After TM was implemented, the offshore load reduced by nearly 50 percent (to 148 tons BOD per day). Scott's contribution to total loading increased from 62 to 99 percent.

During winter 1978, both industries ceased discharging due to strike action. Final major load reduction occurred in January 1980 when the Scott Paper Company's secondary treatment facility was activated. Nearshore loads dropped over 75 percent. However, the offshore load dropped by nearly 97 percent. At the end of the study, the remaining load was split; about 64 percent was directed to the East Waterway while the remaining 36 percent passed through the deepwater diffuser.

Data obtained from seining is shown in Table 4. Trends for water quality and species diversity are summarized in Table 5.

Significant increases in pH occurred at all stations (Figure 4). Likewise, all stations showed significant decreases in SSL (Figure 5). Values for pH appeared to have a natural seasonal component. They were low in winter and

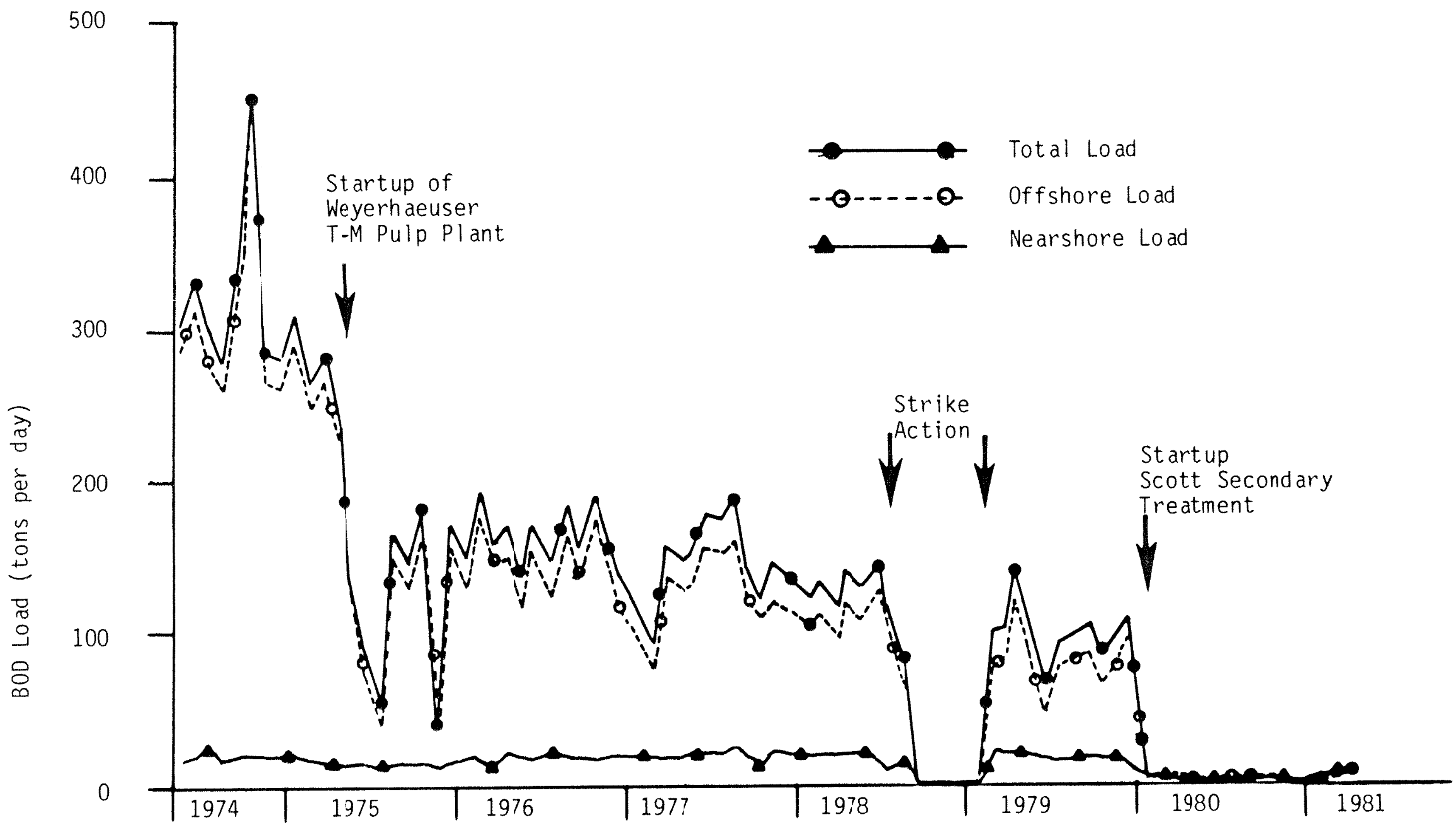

Figure 3. Waste loads vs. time from pulp mills into Port Gardner during ECOBAM 1974 - 1981.

Table 3. Distribution of BOD loads from the Everett paper mills into Port Gardner waters. Values are averages. Data were obtained from industry sources (refer to Figure 3).

Time Intervals	Offshore (Deepwater Diffuser)				Combined Offshore	Nearshore	Offshore and Nearshore Total	Scott Paper Company	
	Scott Paper Company		Weyerhaeuser Company			Scott Company Exclusively			
	(Tons/day BOD)	% Total	(Tons/day BOD)	% Total	(Tons/day BOD)	(Tons/day BOD)	(Tons/day BOD)	Percent Scott/Total	Nearshore/Offshore
May 1974 - July 1975[1/]	183	59	125	41	308	18	326	62	0.06
August 1975 - October 1975	147	>99	1	<1	148	18	166	99	0.12
November 1975 - August 1978[2/]	123	>98	2	<2	125	18	143	99	0.14
September 1978 - January 1979	- - - - - - - - - - - - - - - - -Strike Action; No Discharge From Either Mill- -								
February 1979 - December 1979	80	98	2	2	82	19	101	98	0.19
January 1980 - March 1981[3/]	1.6	70	0.7	30	2.3	4.1	6.4	89	1.78

1/Weyerhaeuser Company TM process commences May 1975.
2/Weyerhaeuser Company shut down five times; Scott discharge continues.
3/Scott treatment plant started January 1980; Weyerhaeuser company TM plant shut dowen permanently December 1980.

Table 4. Summary of species found during monthly seining at beach and deep stations during ECOBAM. The presence of a species is indicated by an "X". Closed circles indicate months in which no sampling was performed.

Common Name (Taxonomic Name)	1974 MJJASOND	1975 JFMAMJJASOND	1976 JFMAMJJASOND	1977 JFMAMJJASOND	1978 JFMAMJJASOND	1979 JFMAMJJASOND	1980 JFMAMJJASOND	1981 JFM
					●		● ●	●
Station ECB101								
Pacific sanddab (*Citharichthys sordidus*)							XX	
Butter sole (*Isopsetta isolepsis*)			X					
Rock sole (*Lepidopsetta bilineata*)	X	X	X X X X		X X			
English sole (*Parophrys vetulus*)	X XX	X XX XX XX	XX XXXXXX XX	XXX XXXX XX	X XXX XXXX X	XX XXX XX	XX XX X	X
Starry flounder (*Platichthys stellatus*)	XX XX XX	XXXXXXXXXXXX	XXXXXXXXXX X	X XXXXXXXX	XX X XXXX X	XXXXXXXXXX	XXX XXX XXX	XX
Sand sole (*Psettichthys melanosticus*)	X		X		XX		X	
Pipe fish (*Syngnathus griseolineatus*)			XX		X X XX X	X XX	X X X	
Pacific sand lance (*Ammodytes hexapterus*)	X	X X XX	XX X XX	X X			XX	
Eelpout (classification unknown)		X	X					
Northern anchovy (*Engraulis mordax mordax*)			X					
Pacific herring (*Clupea harengus pallasi*)	X		X X X XX	XX	XXX X X	X X	X X XX	X
Pink salmon (*Oncorhynchus gorbuscha*)	X X	X	XX	X	XX	X	X X X	
Chum salmon (*Oncorhynchus keta*)	XXXXX X	X XXX	XXX	XXXXXX	XXX	X X	X	X
Coho (silver) salmon (*Oncorhynchus kisutch*)	XXX X	X	X X	X				
Chinook (king) salmon (*Oncorhynchus tshawytscha*)	XXX X	X	X X X		XX	XX		
Rainbow trout (*Salmo gairdneri*)	X							
Surf smelt (*Hypomesus pretiosus pretiosus*)	XXXX XX	XXX XX XX	XX XXXXXX XX	X X X	XX XXXX X	XXXXXX X	XXX X X X	
Pacific tomcod (*Microgadus proximus*)		X	X	X	X	X	X	
Threespine stickleback (*Gasterosteus aculeatus*)	XXX	X	X XX	X	X X X	X X X	XX X XX	
Shiner perch (*Cymatogaster aggregata*)	XXX	XX XXX X	XX XX	X XXX X	XXXXXXXX	X XXXXXX X	X X X XX	
Striped seaperch (*Embiotoca lateralis*)	X						XX	
Pile perch (*Rhacochilus vacca*)	X	XX					X X	
Prickly sculpin (*Cottus asper*)		X	X	X	X	X	X	
Pacific staghorn sculpin (*Leptocottus armatus*)	XXXXXXX	XXXXXXXXXXXX	XXXXXXXXXXXX	XXXXXXXXXXXX	XXXXXXXXXX X	XXXXXXXXXXXX	XXXX XXX XXX	XX
Tidepool sculpin (*Oligocottus maculosus*)							X X	
Blenny (classification unknown)							X	
Arrow goby (*Clevelandia ios*)		X X	X	X	X	X	X	
Dungeness crab (*Cancer magister*)	X X		X	X XXX	X X	X X X		
Purple shore crab (*Hemigrapsus mudus*)				X	X	X X	X	
Crago shrimp (*Crangon* sp.)	X	XXX XXX	XXXXXXX XX	XXX X X XX	XX XX X	XX X XX	XX X X XXX	XX
Total number of species	7 8 7 7	4 5 8 4 6 6	7 6 12 5 8 11	5 6 6 7 4 5	6 4 6 8 5 -	3 8 7 7 5 4	3 5 - 6 - 7	- 6
	8 9 3 5	3 8 6 6 4 11	6 10 9 7 4 7	4 2 8 7 4 8	6 12 5 5 8 10	5 5 7 6 5 8	8 7 10 9 9 9	3

Table 4 - continued.

Common Name (Taxonomic Name)	1974 MJJASOND	1975 JFMAMJJASOND	1976 JFMAMJJASOND	1977 JFMAMJJASOND	1978 JFMAMJJASOND	1979 JFMAMJJASOND	1980 JFMAMJJASOND	1981 JFM
Station ECB102								
Pacific sanddab (Citharichthys sordidus)				X			X	X
Rock sole (Lepidopsetta bilineata)	X X	X X						
Yellowfin sole (Limanda aspera)		X						
English sole (Parophrys vetulus)		X XX X	X X XX X	XX	X X X	XX X X X	X X X	X
Starry flounder (Platichthys stellatus)	XXXXX XX	XXXXXXX XXX	X XX XXXXX X	X X X XXX	X XXXXX X	X XX XXXX	XXXX X X	X
Pipe fish (Syngnathus griseolineatus)		X		X XX	X	XX	X	
Pacific sand lance (Ammodytes hexapterus)		X				X	X	
Eelpout (classification unknown)		X	X					
Pacific herring (Clupea harengus pallasi)		X	X	X	X	X	X	X
Pink salmon (Oncorhynchus gorbuscha)	X	X	X	X	XX	X	XXX	
Chum salmon (Oncorhynchus keta)	XXX	X XXX	XX	XXX X	XXX X	XXXX	XX	
Coho (silver) salmon (Oncorhynchus kisutch)	X	X X	X X X					
Chinook (king) salmon (Oncorhynchus tshawytscha)	X	X X	X			X		
Surf smelt (Hypomesus pretiosus pretiosus)	X XX XX	XXXX XX XX	XX X XXX	XXXX X	X X	X X X	XXXX X X	
Pacific hake (Merluccius productus)			X					
Pacific tomcod (Microgadus proximus)		X						
Threespine stickleback (Gasterosteus aculeatus)	X X X	XXX X	XX	X	X	X		
Shiner perch (Cymatogaster aggregata)	X X	X X XXX	XX X	X XXXX	XX XX X	X XXX X	XXX	
Pile perch (Rhacochilus vacca)		X X					X	
Sharpnose sculpin (Clinocottus acuticeps)		XX	X	X				
Prickly sculpin (Cottus asper)		X	X XX		X			
Buffalo sculpin (Enophrys bison)	X		X	X X				
Pacific staghorn sculpin (Leptocottus armatus)	XX XXXXX	XXXXXXXXXXXX	XXXXXXXXXXXX	XXXXXXXXXXXX	XXXXXXXXXX X	XXXXXXXXXXXX	XXXX XXX X X	XX
Sturgeon poacher (Agonus acipenserinus)		X					X	
Arrow goby (Clevelandia ios)		XX		XX		X X		
Dungeness crab (Cancer magister)		X	X		X			
Purple shore crab (Hemigrapsus nudus)	X							
Crago shrimp (Crangon sp.)	XX XX	XXX XX XX	X X X XX	X X X	X	XX X XXX	X X	XX
Total number of species	8 4 3 5 4 5 3 4	5 6 4 9 3 12 7 6 9 5 4 5	4 3 5 6 2 11 3 6 3 3 4 7	2 4 4 6 3 4 3 5 3 5 4 6	1 3 4 3 4 - 2 4 3 3 5 8	1 3 3 2 5 3 2 7 5 3 9 7	5 6 1 2 - - 3 6 6 2 4 5	- 5 3

Table 4 - continued.

Common Name (Taxonomic Name)	1974 MJJASOND	1975 JFMAMJJASOND	1976 JFMAMJJASOND	1977 JFMAMJJASOND	1978 JFMAMJJASOND	1979 JFMAMJJASOND	1980 JFMAMJJASOND	1981 JFM
Station ECB103				●	●	●	●	●
Pacific sanddab (*Citharichthys sordidus*)							XX X	
Rock sole (*Lepidopsetta bilineata*)	X	X XXXX		X X	X	X X X	XX X	
Slender sole (*Lyopsetta exilis*)			X					
English sole (*Parophrys vetulus*)	X	X X X XX	XX XX	X X	XX XX X X	XXXXXXX X	X X XX X X	X
Starry flounder (*Platichthys stellatus*)	XXXXXXX	XXXXXXXXXXX	XXXXXXX X	XX X X XX	XX XXXX X	XX X XXXXX X	XXXXX XX XXX	XX
Pipe fish (*Syngnathus griseolineatus*)	X	XXX X XX	X X	XX	X X	X XX	X	
Pacific sand lance (*Ammodytes hexapterus*)		X	X X					
Tube-snout (*Aulorhynchus flavidus*)	X	X						
Pacific herring (*Clupea harengus pallasi*)	X		X X		X X	X X	XX	XX
Pink salmon (*Oncorhynchus gorbuscha*)	X		X	XX	XX X		X XXX	
Chum salmon (*Oncorhynchus keta*)	XXXX	XXXXX	XXXX	XXXXXX	X XX	X XXX	XX	X
Coho (silver) salmon (*Oncorhynchus kisutch*)	XX	X X	X XX	X	X	X		
Chinook (king) salmon (*Oncorhynchus tshawytscha*)	XXX X	XX X	XX	X	X	XX		
Coastal cutthroat trout (*Salmo clarki clarki*)	X	X				X		
Rainbow trout (*Salmo gairdneri*)	X		X					
Surf smelt (*Hypomesus pretiosus pretiosus*)	X X X	XX X X XX	X X X XX	XX X	X X X	X X	X XX X	XX
Pacific hake (*Merluccius productus*)						X		
Pacific tomcod (*Microgadus proximus*)		X	X		X	X		
Walleye pollock (*Theragra chalcogramma*)		X						
Threespine stickleback (*Gasterosteus aculeatus*)	X X XX	X XX X		X	X	X X		
Shiner perch (*Cymatogaster aggregata*)	X XXX	XXXXXXX	X XXXXX	XXX XX X	XXXXX X	XX XXX X	X XXXX XX	
Striped seaperch (*Embiotoca lateralis*)		X X	X X X	X	X	X		
Pile perch (*Rhacochilus vacca*)	X	XXX	X	X	X	XX	X X X	
Penpoint gunnel (*Apodichthys flavidus*)						X		
Spinynose sculpin (*Asemichthys taylori*)		X						
Silver-spotted sculpin (*Blepsias cirrhosus*)		X						
Sharpnose sculpin (*Clinocottus acuticeps*)		XX	X	X X	X X	XX		
Prickly sculpin (*Cottus asper*)		XX X			X	XX X		
Buffalo sculpin (*Enophrys bison*)		X XX X	X	X X	X X	X		
Pacific staghorn sculpin (*Leptocottus armatus*)	XXXXXXX	XXXX XXXXXXX	XXXXXXXXXXX	XXX XXXX XX	XX XXXXXXX X	XX XXXXXXXXX	XXXXXXXX XXX	XX
Tidepool sculpin (*Oligocottus maculosus*)							XX	X
Blenny (classification unknown)		X						X
Arrow goby (*Clevelandia ios*)		X		XX	X X			
Dungeness crab (*Cancer magister*)		X X X	X X	X		X		
Purple shore crab (*Hemigrapsus nudus*)		X		X	X		X	
Crago shrimp (*Crangon* sp.)	X	XX X X X	XX X	X X	X	XX X	XX X X XX	XX
Total number of species	3 6 9 6 3 11 6 1	3 6 13 0 7 12 8 4 12 5 6 10	5 6 7 9 4 7 2 6 6 5 1 5	- 4 5 5 7 5 6 3 3 6 2 7	1 5 4 10 5 - 1 4 7 7 5 9	3 - 7 4 6 2 5 6 10 8 6 13	4 2 5 10 - 6 7 4 8 6	- 8 6

Table 4 - continued.

Common Name (Taxonomic Name)	1974 MJJASOND	1975 JFMAMJJASOND	1976 JFMAMJJASOND	1977 JFMAMJJASOND	1978 JFMAMJJASOND	1979 JFMAMJJASOND	1980 JFMAMJJASOND	1981 JFM
Station ECB104		●		●●●●	● ●●●	● ●●●●	● ●	●
Pacific sanddab (Citharichthys sordidus)			X X				X X	
Rock sole (Lepidopsetta bilineata)		X	X	X			X	
English sole (Parophrys vetulus)	X X	X X	X XXX	X XX	XX X X	X XX	X XX XX	
Starry flounder (Platichthys stellatus)	XXXXXXXX	XXXXXX X	XXXXXXXXXXXX	XXXX XX	XXXXXX X X	XX X X XX	XXXXXX X X	XX
Sand sole (Psettichthys melanostictus)	X							
Pipe fish (Syngnathus griseolineatus)	X	XX X X	X X	XXX X			XX	
Pacific sand lance (Ammodytes hexapterus)		X		X			X	X
Pacific herring (Clupea harengus pallasi)	X		X		X	X	X	
Pink salmon (Oncorhynchus gorbuscha)	X	X	XXX		XX	X	X X	
Chum salmon (Oncorhynchus keta)	XXX	X XXXX	XXX X	XXX	XXX	X X	X	X
Coho (silver) salmon (Oncorhynchus kisutch)	XX	X	X					
Chinook (king) salmon (Oncorhynchus tshawytscha)	X	XX	X		X X	X	X	
Dolly varden (Salvelinus malma)		X					X	
Coastal cutthroat trout (Salmo clarki clarki)				X	X			
Rainbow trout (Salmo gairdneri)		X						
Surf smelt (Hypomesus pretiosus pretiosus)	X XXX X	X XX X X XX	X XXXX XX	X X X		XX X X X	XXXX X	
Pacific tomcod (Microgadus proximus)			X			X		
Threespine stickleback (Gasterosteus aculeatus)	XX	X X	X X	X	X X		X	X
Shiner perch (Cymatogaster aggregata)	XXXXXX	XX X XXX	XXXXXX	XXX X	X XX	X X X X	XXXXX X	
Striped seaperch (Embiotoca lateralis)		X X	X		X X			
Pile perch (Rhacochilus vacca)		X	X		X			
Penpoint gunnel (Apodichthys flavidus)					X			
Sharpnose sculpin (Clinocottus acuticeps)	X	XX X	X X X	XX X XX	XX	XX	X	
Prickly sculpin (Cottus asper)		X	X X		X	X	X	
Buffalo sculpin (Enophrys bison)					X			
Pacific staghorn sculpin (Leptocottus armatus)	XXXXXXXX	XX X XXXXX	X		X X X	XX X X XX	XXXXX X X X	XX
Tidepool sculpin (Oligocottus maculosus)			X					
Blenny (classification unknown)							XX	X
Arrow goby (Clevelandia ios)	XXX	X X XX	XXXXX X	XXX	X	XX	XX	
Dungeness crab (Cancer magister)		X	X X			X X		
Purple shore crab (Hemigrapsus nudus)				X			X	
Crago shrimp (Crangon sp.)	XXXX	X X XXX	XX X X XXX	XX	X X	X X XX	XXXXXXX X	XX
Total number of species	7 4 6 6 8 5 8 4	3 10 6 - 5 5 4 8 10 4 7 4	3 6 8 7 8 5 1 7 6 5 8 7	1 7 6 - - 6 3 7 4 - - 4	2 6 5 - 1 - 4 6 2 7 - 7	5 - 1 - - 4 5 8 8 - - 9	3 5 7 8 - - 5 9 8 4 5 6	- 7 3

Table 4 - continued.

Common Name (Taxonomic Name)	1974 MJJASOND	1975 JFMAMJJASOND	1976 JFMAMJJASOND	1977 JFMAMJJASOND	1978 JFMAMJJASOND	1979 JFMAMJJASOND	1980 JFMAMJJASOND	1981 JFM
Station ECB201	●	●			● ●		● ●	●●
River lamprey (Lampetra ayresi)			X					
Pipe fish (Syngnathus griseolineatus)	X	X					X	
Pacific sand lance (Ammodytes hexapterus)	X X		X	X X	X	X		
Pacific herring (Clupea harengus pallasi)	XX X	XX	X XXX	X XX	XX	X	X X	
Pink salmon (Oncorhynchus gorbuscha)			X		X		X	
Chum salmon (Oncorhynchus keta)	X	X X	X X	XX	X	X	X	
Coho (silver) salmon (Oncorhynchus kisutch)	X			XX		X	X	
Chinook (king) salmon (Oncorhynchus tshawytscha)					X	X		
Coastal cutthroat trout (Salmo clarki clarki)		X						
Surf smelt (Hypomesus pretiosus pretiosus)		X X	XXXXX	X				
Threespine stickleback (Gasterosteus aculeatus)	X	XX X	X		X	X X X X	X X	
Total number of species	1 - 1 0 3 2 0 2	0 1 2 0 2 0 - 1 2 3 0 0	2 1 2 1 1 0 1 4 2 1 0 0	0 2 5 0 0 0 0 1 2 0 0 0	0 2 0 2 0 0 0 0 2 - - 1	0 0 0 0 0 0 1 2 4 2 0 0	- 0 0 0 - 0 0 2 5 1 0 0	- 0 -

Common Name (Taxonomic Name)	1974 MJJASOND	1975 JFMAMJJASOND	1976 JFMAMJJASOND	1977 JFMAMJJASOND	1978 JFMAMJJASOND	1979 JFMAMJJASOND	1980 JFMAMJJASOND	1981 JFM
Station ECB202	●	●			●		●	●●
Pipe fish (Syngnathus griseolineatus)					X	X		
Pacific sand lance (Ammodytes hexapterus)		X	X	X	X	X		
Northern anchovy (Engraulis mordax mordax)		X						
Pacific herring (Clupea harengus pallasi)	XX XX	XXX	X X	X	XX	XX X	X	
Pink salmon (Oncorhynchus gorbuscha)	X		X		X		X	
Chum salmon (Oncorhynchus keta)	XX	XXX	X X	XX	X	X		
Coho (silver) salmon (Oncorhynchus kisutch)	X X	XX X	X					
Chinook (king) salmon (Oncorhynchus tshawytscha)		X X	X	X	XX	X X		
Surf smelt (Hypomesus pretiosus pretiosus)		X X	XX X	XXX X	X	X		
Threespine stickleback (Gasterosteus aculeatus)		X XXXX	X X X	X X	XX XX	X X XXX X	X X	
Shiner perch (Cymatogaster aggregata)		X	X					
Striped seaperch (Embiotoca lateralis)			X					
Pacific staghorn sculpin (Leptocottus armatus)							X	
Crago shrimp (Crangon sp.)	X		X X					
Total number of species	4 - 1 - 2 1 2 0	1 0 5 4 2 0 - 1 3 4 0 1	2 0 2 2 3 2 1 3 3 0 0 0	0 2 1 3 1 0 1 2 1 0 0 0	0 1 5 1 0 1 1 0 2 1 - 1	1 1 0 3 1 0 0 2 2 3 2 0	0 1 1 1 - 0 0 2 0 0 0 0	- 0 -

Table 4 - continued.

Common Name (Taxonomic Name)	1974 MJJASOND	1975 JFMAMJJASOND	1976 JFMAMJJASOND	1977 JFMAMJJASOND	1978 JFMAMJJASOND	1979 JFMAMJJASOND	1980 JFMAMJJASOND	1981 JFM
Station ECB203	●	●			●		●	●●
Starry flounder (Platichthys stellatus)		XX X						
Pipe fish (Syngnathus griseolineatus)				X		X		
Pacific sand lance (Ammodytes hexapterus)	X	XXX	X	X XX				
Northern anchovy (Engraulis mordax mordax)			X					
Pacific herring (Clupea harengus pallasi)	X XX	XXX	X XXX	X XXXX	XX	X XXXX	X X	
Pink salmon (Oncorhynchus gorbuscha)			X X	X	X	X		
Chum salmon (Oncorhynchus keta)	XX	XX	X X	XX		X		
Coho (silver) salmon (Oncorhynchus kisutch)	X	X X		X		X		
Chinook (king) salmon (Oncorhynchus tshawytscha)	X	XX		X	XX	XXX		
Surf smelt (Hypomesus pretiosus pretiosus)		X	XX	X X X	X X	X		
Threespine stickleback (Gasterosteus aculeatus)	X XX	X X X XXXX X	XX	X X X XX	XXXX X	X XX XXX X	X X	
Shiner perch (Cymatogaster aggregata)						X		
Pacific staghorn sculpin (Leptocottus armatus)							X	
Total number of species	4 - 3 0 2 2 0 0	1 2 3 3 1 1 - 1 5 3 1 2	0 0 1 3 3 0 0 2 2 1 0 0	0 2 2 3 4 1 2 2 3 2 0 2	1 2 0 2 0 1 2 1 2 - 0 1	1 1 3 1 3 1 0 1 3 4 2 1	1 1 0 0 - 0 0 2 0 1 0 0	- 0 -

Common Name (Taxonomic Name)	1974 MJJASOND	1975 JFMAMJJASOND	1976 JFMAMJJASOND	1977 JFMAMJJASOND	1978 JFMAMJJASOND	1979 JFMAMJJASOND	1980 JFMAMJJASOND	1981 JFM
Station ECB204	● ●	●●			● ●		●	●●
Pacific sand lance (Ammodytes hexapterus)	X	X X	X X	X		X		
Pacific herring (Clupea harengus pallasi)	X X	X	XX	XXX	X	XXXX	XX	
Pink salmon (Oncorhynchus gorbuscha)		X	X		X	XX		
Chum salmon (Oncorhynchus keta)	XX	XX X	X		X			X
Coho (silver) salmon (Oncorhynchus kisutch)	X	X X						
Chinook (king) salmon (Oncorhynchus tshawytscha)		X X	XX	XX	XX	X X		
Surf smelt (Hypomesus pretiosus pretiosus)			X X XX	X		X X		
Threespine stickleback (Gasterosteus aculeatus)		X X X	X X	X XXX X	X X X	X XXX XXX	X X	
Shiner perch (Cymatogaster aggregata)					X X	X		
Prickly sculpin (Cottus asper)						X		
Total number of species	3 - - 0 1 1 0 1	- 1 3 0 0 0 - 0 4 5 0 1	2 0 2 1 2 0 0 2 0 4 1 0	0 0 0 3 2 0 0 1 0 4 1 1	1 1 1 3 1 1 0 0 2 - - 0	0 1 0 2 1 2 2 0 2 6 2 2	0 1 1 0 - 0 0 1 0 0 1 0	- 1 -

Table 4 - continued.

Common Name (Taxonomic Name)	1974								1975											
	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Station ECB205			●																	
Starry flounder (Platichthys stellatus)																				
Pacific sand lance (Ammodytes hexapterus)																				
Northern anchovy (Engraulis mordax mordax)																				
Pacific herring (Clupea harengus pallasi)	X			X	X	X	X									X	X			
Pink salmon (Oncorhynchus gorbuscha)	X	X											X		X					
Chum salmon (Oncorhynchus keta)	X	X												X		X				
Coho (silver) salmon (Oncorhynchus kisutch)																				
Chinook (king) salmon (Oncorhynchus tshawytscha)													X			X				
Coastal cutthroat trout (Salmo clarki clarki)																				
Surf smelt (Hypomesus pretiosus pretiosus)																				X
Threespine stickleback (Gasterosteus aculeatus)					X	X	X	X	X			X	X			X	X		X	
Shiner perch (Cymatogaster aggregata)					X															
Pile perch (Rhacochilus vacca)					X															
Pacific staghorn sculpin (Leptocottus armatus)																				
Blenny (classification unknown)					X															
Crago shrimp (Crangon sp.)					X															
Total number of species	3	2	-	1	6	2	2	1	1	0	0	1	3	1	1	4	2	0	1	1

Common Name (Taxonomic Name)	1975												1977											
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Station ECB205																								
Starry flounder (Platichthys stellatus)																X								
Pacific sand lance (Ammodytes hexapterus)																								
Northern anchovy (Engraulis mordax mordax)																	X							
Pacific herring (Clupea harengus pallasi)									X									X	X				X	
Pink salmon (Oncorhynchus gorbuscha)															X									
Chum salmon (Oncorhynchus keta)						X																		
Coho (silver) salmon (Oncorhynchus kisutch)																	X							
Chinook (king) salmon (Oncorhynchus tshawytscha)									X								X							
Coastal cutthroat trout (Salmo clarki clarki)						X				X														
Surf smelt (Hypomesus pretiosus pretiosus)	X	X			X																		X	
Threespine stickleback (Gasterosteus aculeatus)			X	X			X				X	X						X		X		X	X	
Shiner perch (Cymatogaster aggregata)																								
Pile perch (Rhacochilus vacca)																								
Pacific staghorn sculpin (Leptocottus armatus)															X									
Blenny (classification unknown)																								
Crago shrimp (Crangon sp.)																								
Total number of species	1	1	1	1	1	2	1	0	2	1	1	1	0	0	2	1	3	2	1	1	0	1	3	0

Common Name (Taxonomic Name)	1978												1979											
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Station ECB205								●		●							●							
Starry flounder (Platichthys stellatus)																								
Pacific sand lance (Ammodytes hexapterus)																			X	X	X			
Northern anchovy (Engraulis mordax mordax)																								
Pacific herring (Clupea harengus pallasi)						X	X				X							X	X	X	X	X	X	
Pink salmon (Oncorhynchus gorbuscha)					X																			
Chum salmon (Oncorhynchus keta)					X	X												X						
Coho (silver) salmon (Oncorhynchus kisutch)					X																			
Chinook (king) salmon (Oncorhynchus tshawytscha)					X	X												X						
Coastal cutthroat trout (Salmo clarki clarki)																								
Surf smelt (Hypomesus pretiosus pretiosus)			X								X													
Threespine stickleback (Gasterosteus aculeatus)			X						X		X	X	X			X		X		X	X	X	X	X
Shiner perch (Cymatogaster aggregata)																				X				
Pile perch (Rhacochilus vacca)																								
Pacific staghorn sculpin (Leptocottus armatus)																								
Blenny (classification unknown)																								
Crago shrimp (Crangon sp.)						X																		
Total number of species	0	0	2	0	4	4	1	-	1	-	3	1	1	0	0	1	-	4	2	4	3	2	2	1

Common Name (Taxonomic Name)	1980												1981		
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
Station ECB205									●				●	●	
Starry flounder (Platichthys stellatus)															
Pacific sand lance (Ammodytes hexapterus)								X							
Northern anchovy (Engraulis mordax mordax)															
Pacific herring (Clupea harengus pallasi)	X				X	X		X		X	X				
Pink salmon (Oncorhynchus gorbuscha)															
Chum salmon (Oncorhynchus keta)															X
Coho (silver) salmon (Oncorhynchus kisutch)															
Chinook (king) salmon (Oncorhynchus tshawytscha)															
Coastal cutthroat trout (Salmo clarki clarki)															
Surf smelt (Hypomesus pretiosus pretiosus)				X											
Threespine stickleback (Gasterosteus aculeatus)	X		X			X				X	X				
Shiner perch (Cymatogaster aggregata)															
Pile perch (Rhacochilus vacca)															
Pacific staghorn sculpin (Leptocottus armatus)															
Blenny (classification unknown)															
Crago shrimp (Crangon sp.)															X
Total number of species	2	0	1	1	1	2	0	2	-	2	2	0	-	-	2

Table 5. Results of trend analysis performed by the Environmental Protection Agency, Region X, on data collected during ECO3AM monitoring (trends are considered significant for p = 0.05).

Parameter	Station	Rho	Prob. (2-tailed)	n	Conclusion
pH (S.U.)	ECB101	0.419	0.000	75	Increasing Trend
	ECB102	0.238	0.042	74	Increasing Trend
	ECB103	0.364	0.002	75	Increasing Trend
	ECB104	0.298	0.013	70	Increasing Trend
	ECB201	0.459	0.000	73	Increasing Trend
	ECB202	0.407	0.001	74	Increasing Trend
	ECB203	0.354	0.002	74	Increasing Trend
	ECB204	0.242	0.043	71	Increasing Trend
	ECB205	0.287	0.015	73	Increasing Trend
PBI (mg/L)	ECB101	-0.514	0.000	77	Decreasing Trend
	ECB102	-0.371	0.001	76	Decreasing Trend
	ECB103	-0.447	0.000	79	Decreasing Trend
	ECB104	-0.381	0.001	73	Decreasing Trend
	ECB201	-0.570	0.000	75	Decreasing Trend
	ECB202	-0.534	0.000	76	Decreasing Trend
	ECB203	-0.397	0.001	76	Decreasing Trend
	ECB204	-0.335	0.004	74	Decreasing Trend
	ECB205	-0.276	0.018	75	Decreasing Trend
D.O. (mg/L) 1/	ECB101	0.147	0.179	77	No Trend
	ECB102	0.061	0.578	76	No Trend
	ECB103	-0.042	0.700	78	No Trend
	ECB104	0.081	0.461	70	No Trend
	ECB201	0.284	0.010	75	Increasing Trend
	ECB202	0.243	0.027	76	Increasing Trend
	ECB203	0.290	0.008	76	Increasing Trend
	ECB204	0.250	0.023	73	Increasing Trend
	ECB205	0.134	0.222	75	No Trend
Salinity (ppt)	ECB101	+0.260	0.021	79	Increasing Trend
	ECB102	+0.274	0.016	78	Increasing Trend
	ECB103	+0.218	0.052	79	No Trend
	ECB104	+0.168	0.150	73	No Trend
	ECB201	+0.153	0.186	75	No Trend
	ECB202	+0.154	0.173	78	No Trend
	ECB203	+0.104	0.360	77	No Trend
	ECB204	+0.115	0.320	75	No Trend
	ECB205	+0.137	0.234	75	No Trend

Parameter	Station	Rho	Prob. (2-tailed)	n	Conclusion
Temperature (°C) 1/	ECB101	-0.221	0.044	80	Decreasing Trend
	ECB102	-0.147	0.181	79	No Trend
	ECB103	-0.063	0.564	80	No Trend
	ECB104	-0.121	0.268	74	No Trend
	ECB201	-0.272	0.013	77	Decreasing Trend
	ECB202	-0.117	0.287	78	No Trend
	ECB203	-0.180	0.101	78	No Trend
	ECB204	-0.161	0.142	76	No Trend
	ECB205	-0.291	0.008	76	Decreasing Trend
Turbidity (NTU)	ECB101	-0.295	0.010	77	Decreasing Trend
	ECB102	-0.145	0.205	77	No Trend
	ECB103	-0.132	0.246	78	No Trend
	ECB104	-0.048	0.683	72	No Trend
	ECB201	-0.323	0.005	75	Decreasing Trend
	ECB202	0.000	1.000	76	No Trend
	ECB203	0.090	0.427	76	No Trend
	ECB204	0.016	0.893	74	No Trend
	ECB205	0.081	0.472	74	No Trend
Secchi (m)	ECB201	0.076	0.574	56	No Trend 2/
	ECB202	0.104	0.445	55	No Trend 2/
	ECB203	0.248	0.071	54	No Trend 2/
	ECB204	0.416	0.003	53	Increasing Trend 2/
	ECB205	-0.210	0.137	51	Decreasing Trend 2/
Species Diversity	ECB101	0.055	0.629	79	No Trend
	ECB102	-0.191	0.094	78	No Trend
	ECB103	0.314	0.006	78	Increasing Trend
	ECB104	-0.012	0.922	67	No Trend 2/
	ECB201			36 3/	
	ECB202	-0.252	0.085	48	No Trend 2/
	ECB203	-0.222	0.102	55	No Trend 2/
	ECB204	-0.088	0.570	43	No Trend 2/
	ECB205	0.058	0.655	60	No Trend 2/

1/ Deseasonalized data used in trend analysis.

2/ Warning - more than 20- percent of dates not sampled; trend conclusions for Rho stats are uncertain.

3/ Less than 50 percent of dates samples; analysis not performed.

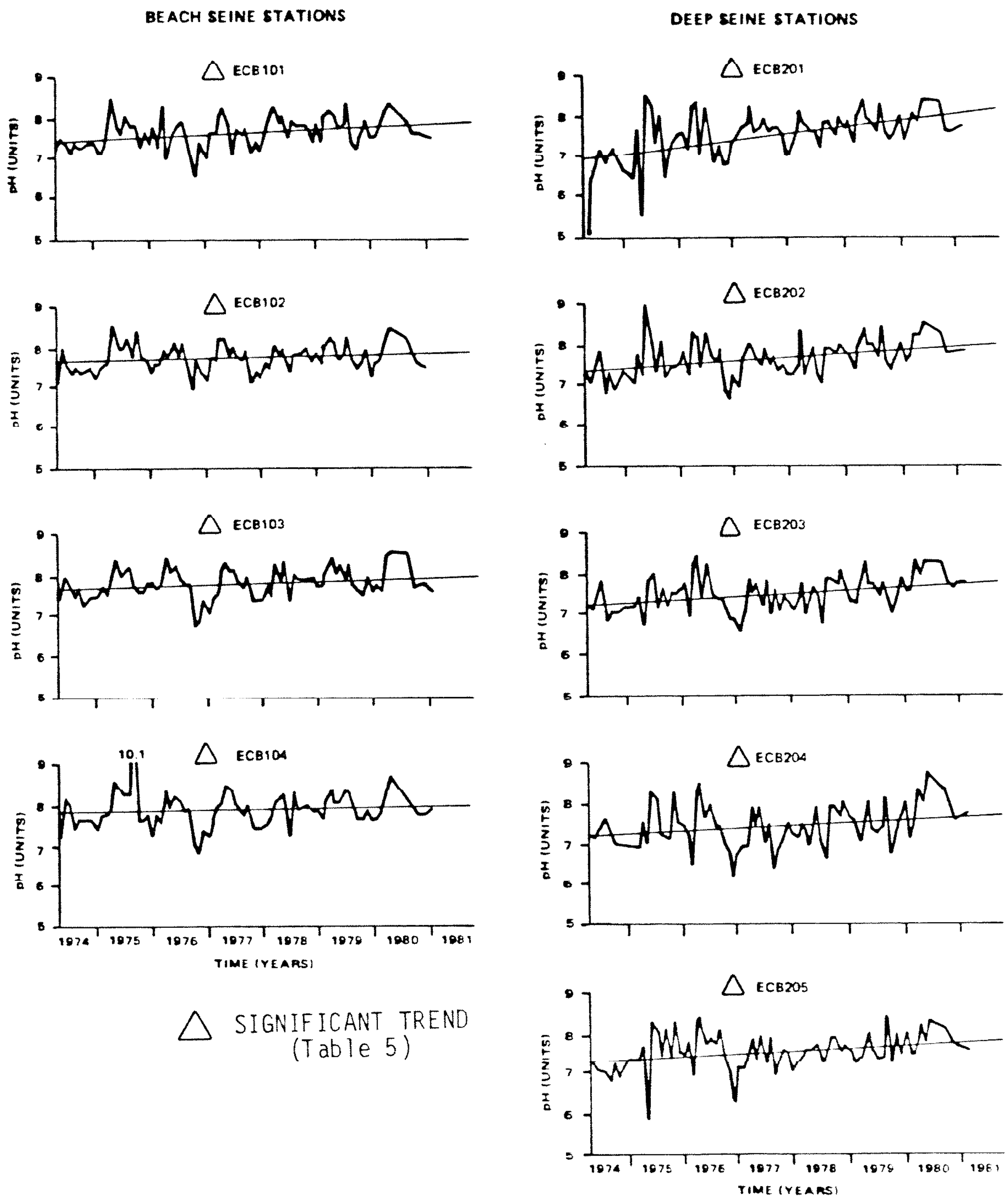

Figure 4. pH versus time from ECOBAM beach and deep seine stations.

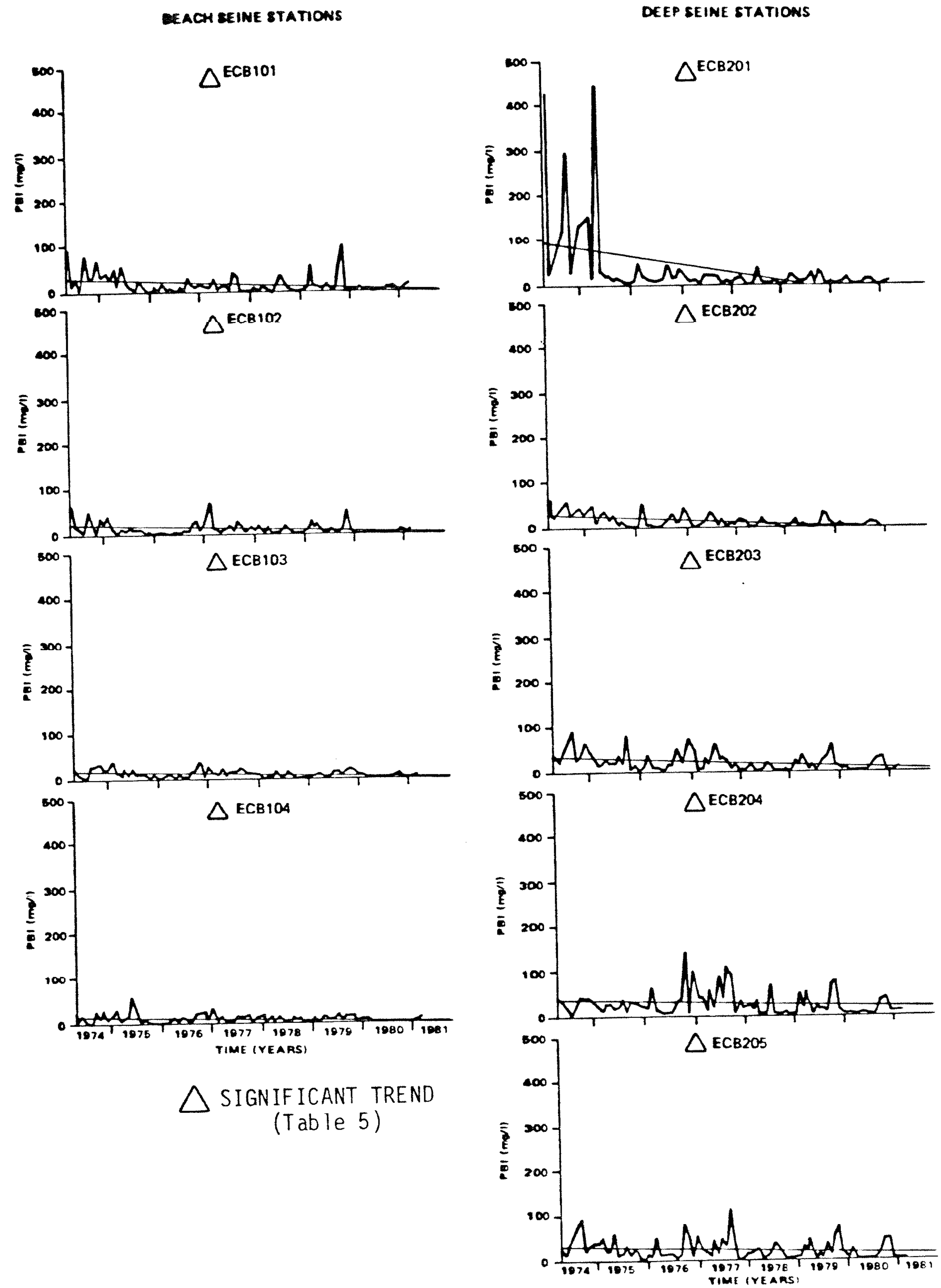

Figure 5. Spent sulfite liquor as PBI versus time from ECOBAM beach and deep seine stations.

high in summer. River flow does not appear to be an important factor in the seasonal change in pH. This will be discussed later.

Levels of pH do not seem to coincide with the treatment milestones shown in Figure 3. However, in addition to the milestones, there was a gradual decline of SSL and bleach plant discharge between 1974 and 1979. Both types of discharge are strongly acidic (pH = 2-3 units) and were directed mostly to the deepwater diffuser (T. Bechtel, Environmental Manager, Scott Paper Company). However, direct comparison between pH in receiving water and discharge is not possible because discharge pH was not routinely monitored until the advent of biological treatment in 1980. By that time, pH was maintained near neutrality.

Four of five deep-seine stations showed significant improvement in oxygen levels (Figure 6). The innermost deep-seine site (ECB205) has shown no improvement. This may be due to oxygen demand exerted from the silt trap outfall (Figure 2, Table 1) coupled with minimum tidal exchange at that location.

Figure 7 shows downward temperature regression lines at all ECOBAM stations, although the trend was significant at only three of the nine sites. Salinity (Figure 8) also showed upward regression lines, but significance existed at only two sites. But the fact that all sites showed the same pattern for temperature and salinity suggests the possibility of a regional trend unrelated to the paper industry discharges.

Turbidity and Secchi disk depth both measure the transparency of water to light. Turbidity decreased significantly at Stations 101 and 201 (Figure 9). Both these sites are close to the Weyerhaeuser mill (Figures 1 and 2). Improvement in turbidity may be related to process changes and the ultimate closure of the mill. Generally, the turbidity data were near the lower sensitivity limit which contributed to the lack of significant trends. Secchi disk depth increased significantly at ECO204 and decreased at ECB205. The remaining sites showed no significant pattern.

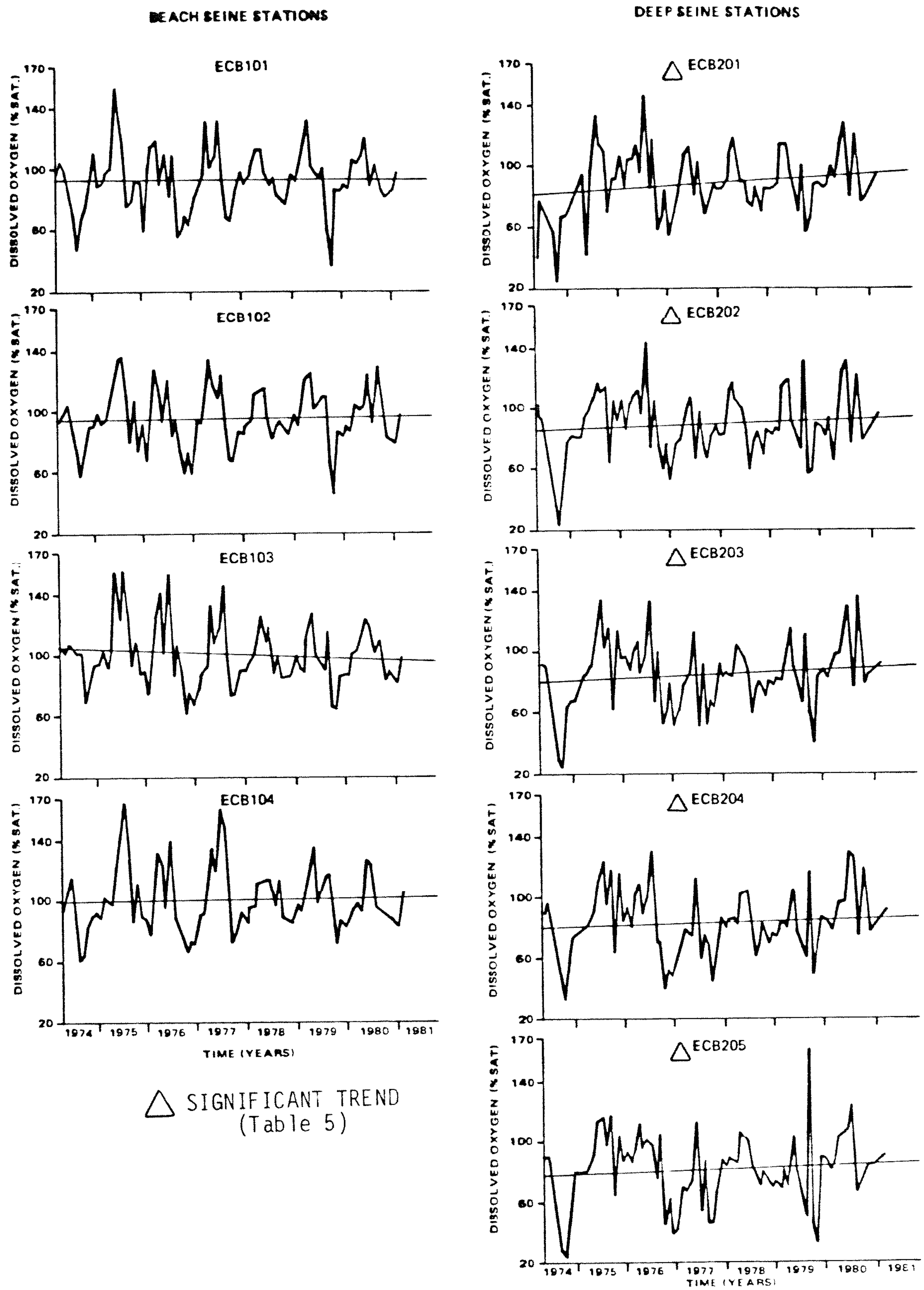

Figure 6. Dissolved oxygen versus time from ECOBAM beach and deep seine stations.

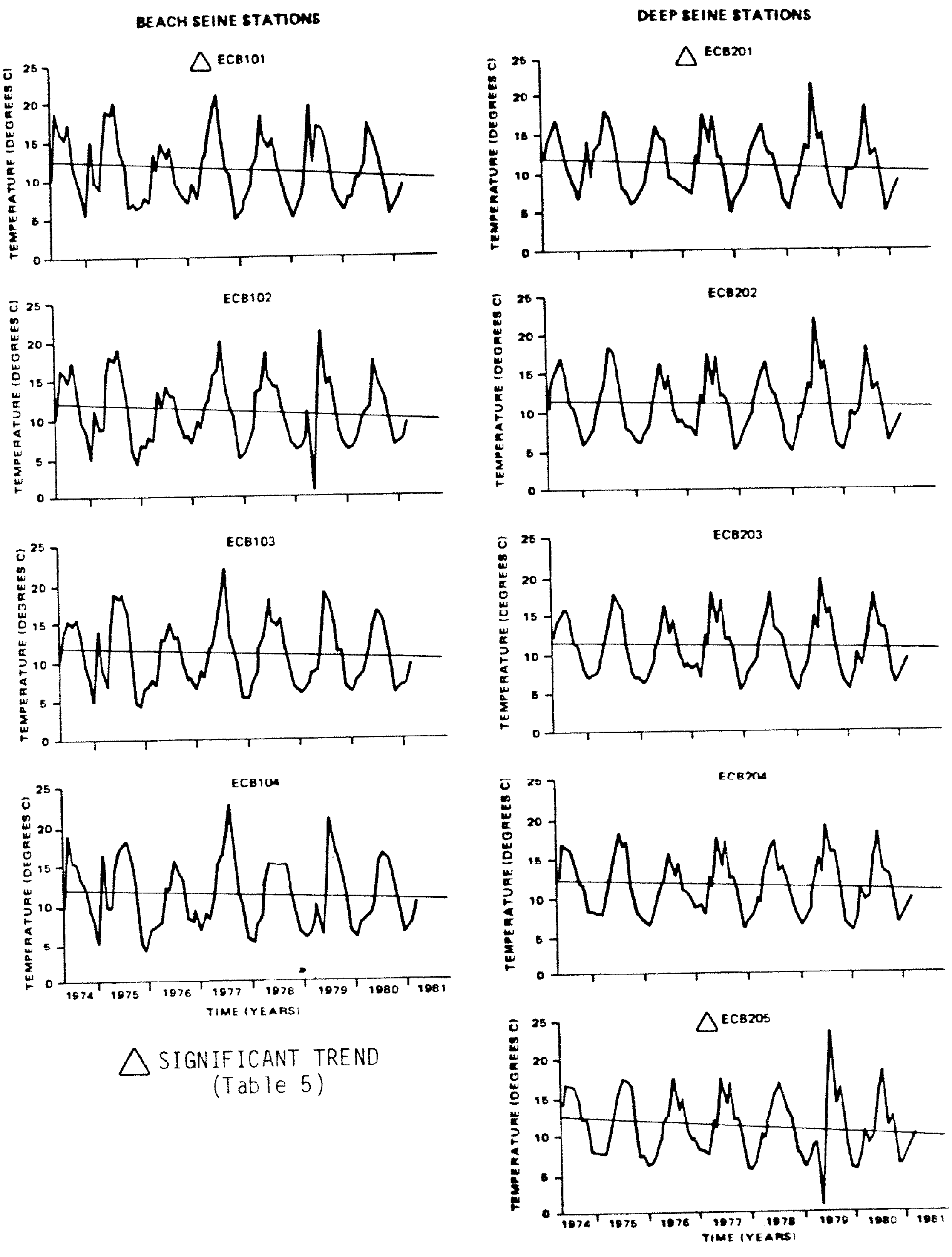

Figure 7. Temperature versus time from ECOBAM beach and deep seine stations.

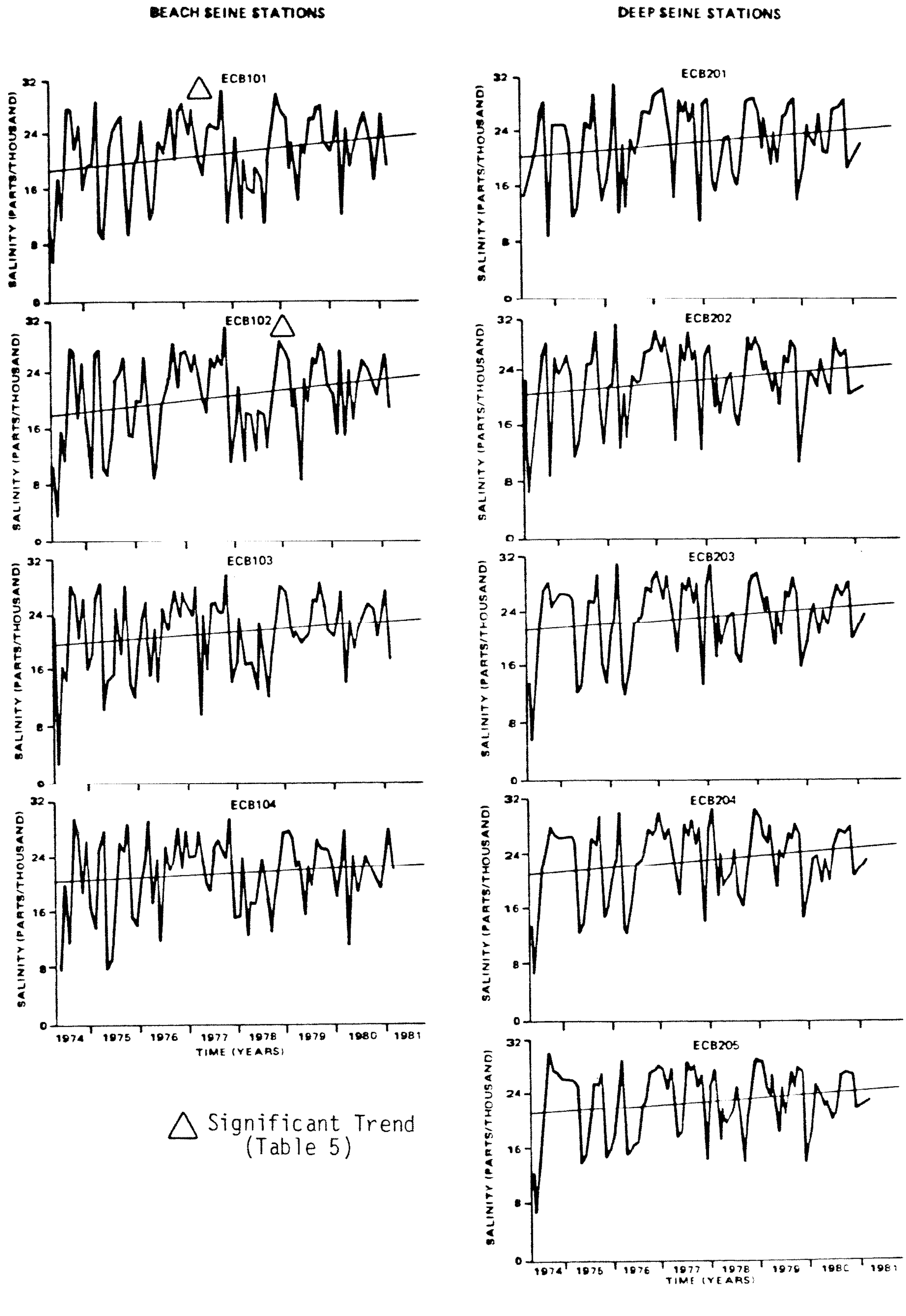

Figure 8. Salinity versus time from ECOBAM beach and deep seine stations (trend analysis was not done).

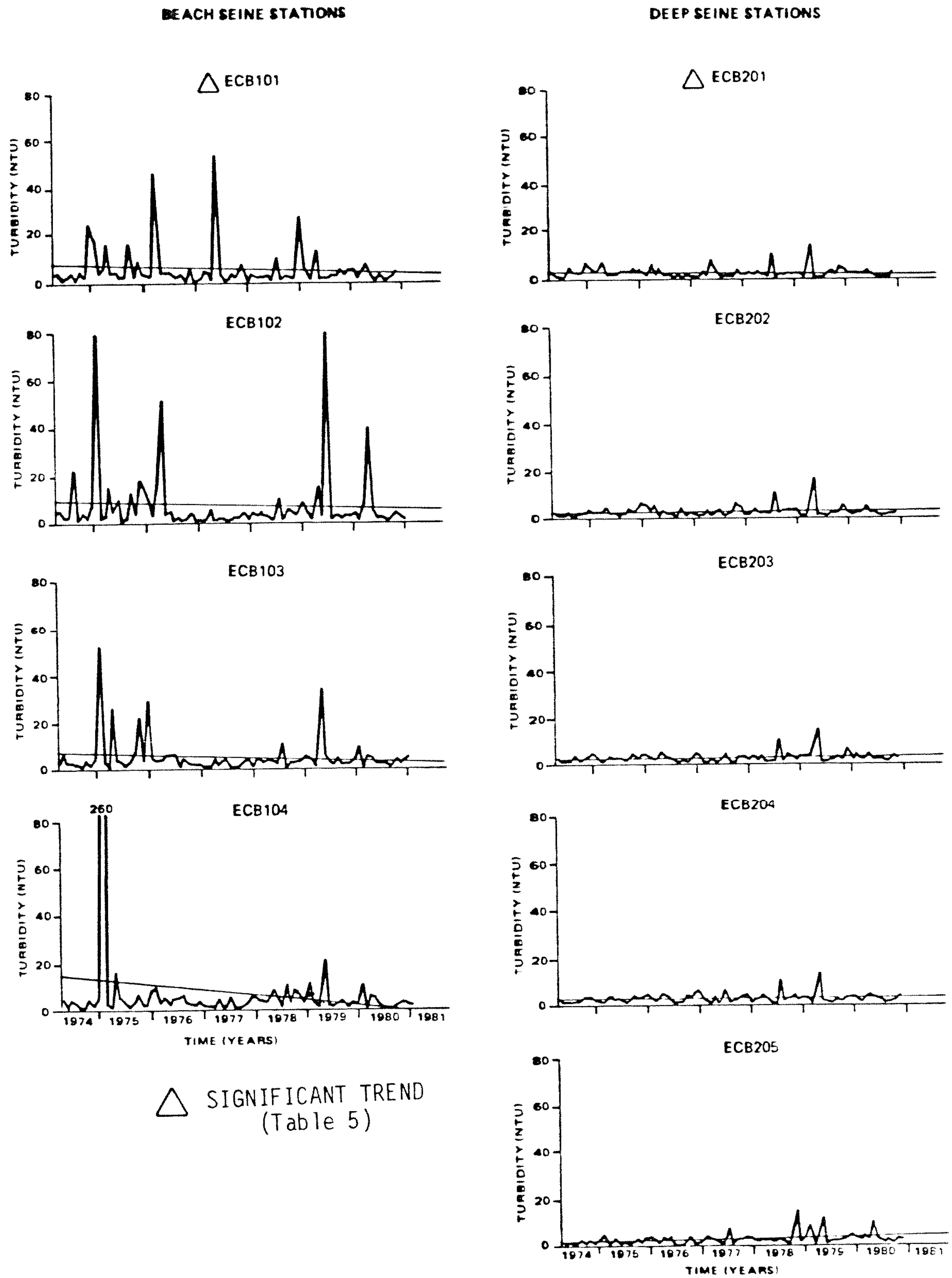

Figure 9. Turbidity versus time from ECOBAM beach and deep seine stations.

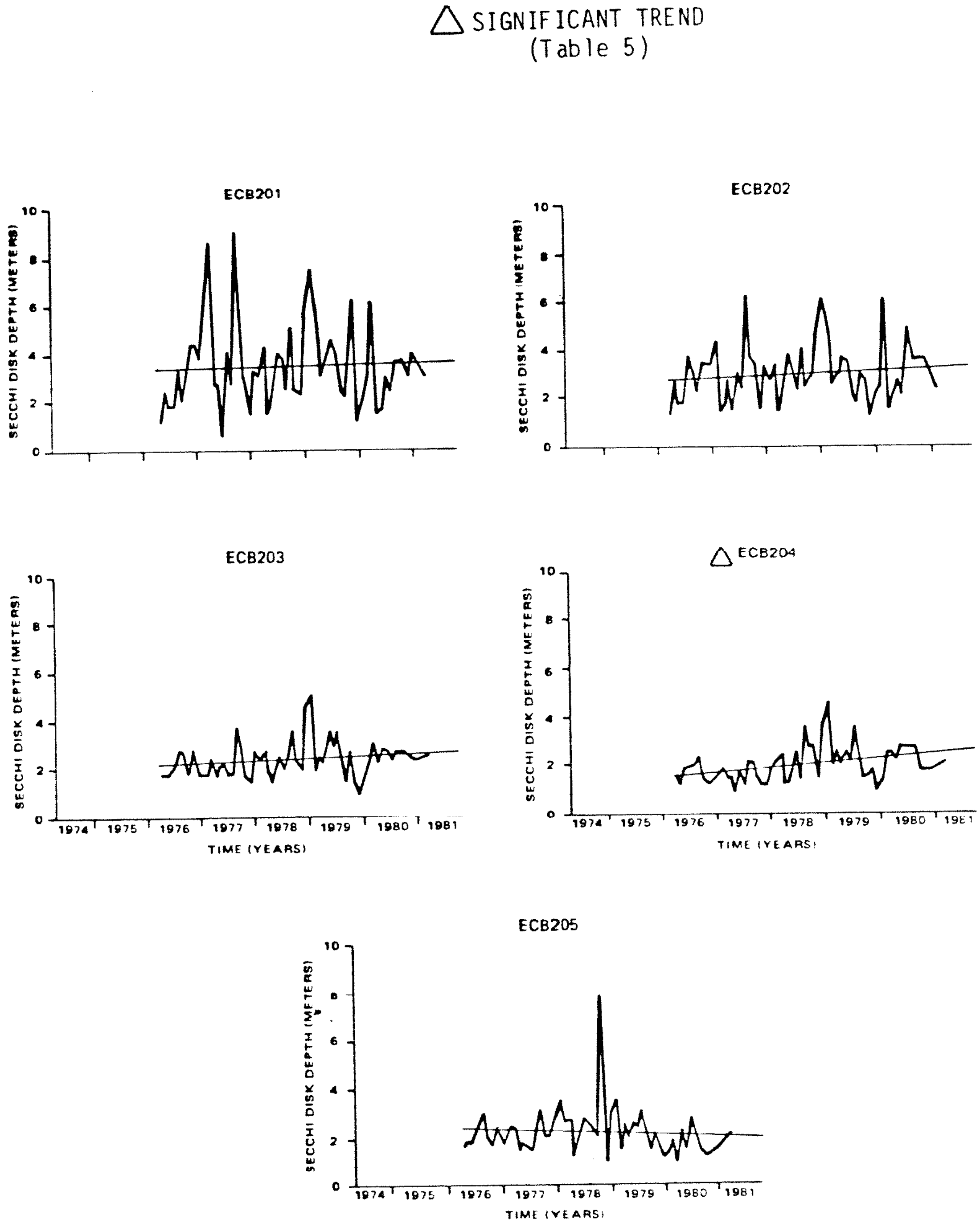

Figure 10. Secchi disk depth versus time from ECOBAM beach and deep seine stations.

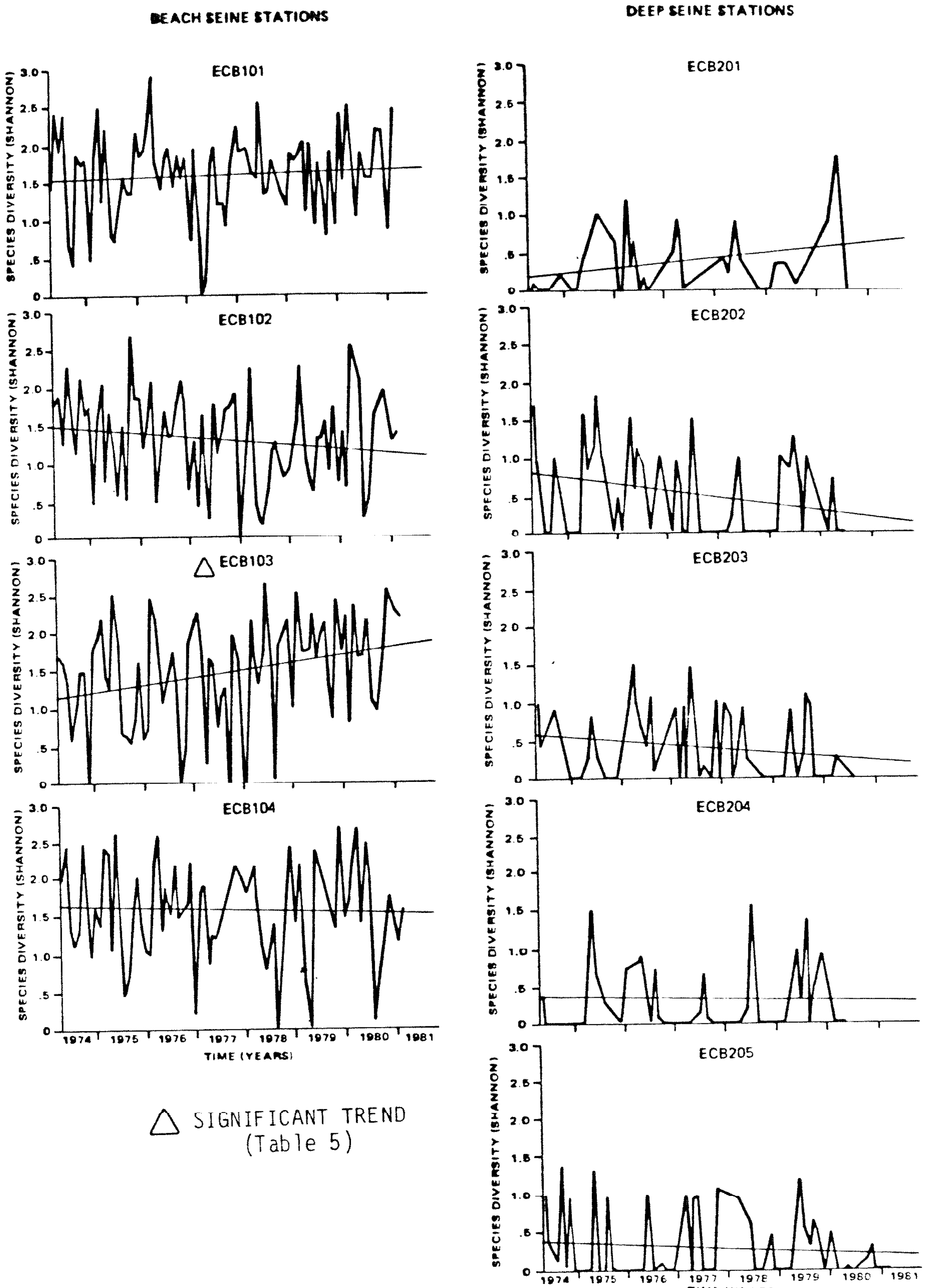

Figure 11. Species diversity versus time from ECOBAM beach and deep seine stations.

Significant change in species diversity occurred at beach-seine site ECB103 only. The sampling sites do not share a common seasonal pattern. A list of fish species caught in the beach- and deep-seining zones are shown in Table 4. Far fewer species were caught at the deep stations. Choice of sampling method and variations in seining success were likely factors.

Juvenile salmon and threespine stickleback appeared during spring and summer months. Several organisms appeared to be year-round residents at the beach stations; e.g., English sole, Pacific staghorn, shrimps, and some crabs.

To summarize, there is evidence that SSL levels decreased during the course of ECOBAM. In addition, pH at all stations increased and dissolved oxygen levels increased at four out of the five deepwater stations. These trends coincide with decreasing loads from the paper industries and support the hypothesis that load reductions have resulted in improvements in general water quality.

Table 6 summarizes the results of multiple correlation analyses using Kendall's Tau (Sokal and Rohlf, 1969). The greatest number of significant correlations occurred between BOD loads and SSL. PBI was positively correlated with offshore load at all deep- and beach stations and with total loads at all stations except ECB205. Values for pH were significantly correlated with discharge loads at all deep stations. (Only ECB101 among the beach stations showed significant correlation between pH and waste loads.) There was no significant correlation between dissolved oxygen and any load component at any station. This may be due to the influence of many other factors on dissolved oxygen levels. Secchi depth was correlated with loads at two of the five deep stations where Secchi depth was measured (ECB203 and 204).

The offshore and total loads showed consistently greater correlation with the water quality variables than did nearshore loads. This may be because the offshore load was an order of magnitude greater in volume than the nearshore for the majority of the study and thus much more important mathematically. On the other hand, it may also be evidence that effluent from the deepwater

Table 6. Summary of conclusions[1] from multiple correlation analysis of ECOBAM data using Kendall's Tau. Only results showing significant difference are shown. Complete analysis including critical statistics are found in the Appendix.

	Station	pH (units)	PBI (mg/L)	D.O. (% sat.)	Temp. (°C)	Turb. (NTU)	Secchi Depth (m)	Species Diversity
Offshore Load (tons/day BOD)	ECB101	**	***					
	ECB102		**					
	ECB103		***					*
	ECB104		***		*			
	ECB201	***	***		*			
	ECB202	**	***					*
	ECB203	*	**				*	
	ECB204	*	**				***	
	ECB205	*	*		**			
Total Load (tons/day BOD)	ECB101	**	***					
	ECB102		**					
	ECB103		***					*
	ECB104		***		*			
	ECB201	**	***		*			
	ECB202	**	***					*
	ECB203	**	**			*	*	
	ECB204	*	**				***	
	ECB205	*			**			
pH (S.U.)	ECB101			*	**			
	ECB102			***	***			
	ECB103			***	***			
	ECB104			***	***			
	ECB201			***				
	ECB202			***				
	ECB203			***				
	ECB204			***				
	ECB205			***				
PBI (mg/L)	ECB101	**		**	*			
	ECB102	***		**				
	ECB103	**		*	*	*		*
	ECB104	*						
	ECB201	***		***	*			
	ECB202	***		**				
	ECB203	***		***				
	ECB204	***		***				
	ECB205	***		***				
Turbidity (NTU)	ECB101							
	ECB102			*				
	ECB103		*					
	ECB104							
	ECB201							
	ECB202				*			
	ECB203				**			
	ECB204				**			
	ECB205				***			

[1]Conclusions:
*Significant (0.05 > 0.01)
**Very significant (0.01 > P > 0.001)
***Highly significant (P < 0.001)

discharge found its way into nearshore surface waters via the tide-modified, density-driven estuarine circulation described earlier.

A relationship among SSL, D.O., and pH was apparent in all analyses. Correlation analysis showed significant negative correlation between SSL and pH at all stations and between SSL and D.O. at eight of nine stations. Eldridge and Orlob (1951) and Bartsch, et al. (1967) showed a similar pattern. In a marine ecosystem, a high level of primary production raises D.O. and carbon dioxide is removed from the system. The reduction in CO_2 raises pH (Sverdrup, et al., 1941; Skirrow, 1965). Although background productivity may be a partial explanation, productivity data are lacking. On the other hand, PBI is also correlated with pH and D.O., and the three variables show significant change over time. This may be evidence as noted earlier that increases in pH may be due to reduction of the highly acidic SSL and bleach plant effluents (T. Bechtel, Environmental Manager, Scott Paper Company). The explanation may be a combination of both ideas.

A factor in the seasonal fluctuation of pH may be dilution of marine water by high flow from the Snohomish River. If this was the case, we would expect to see significant positive correlation between salinity and pH (low pH at low salinity, high pH at high salinity). Product-moment correlation coefficients were calculated to test the importance of this factor. Seven out of nine sites showed negative coefficients (ECB101-103, 202-205). The remaining sites (ECB 104, 201) were positive but so small (r=.08, .07, respectively) as to lack significance. Thus, an appropriate correlation between pH and dilution is likely reduced by other interacting factors.

Temperature was positively correlated with pH at all beach stations, but not at deep ones. The increase in pH with temperature at the beach stations may be associated with primary productivity which is maximal during the warm seasons of the year. However, the lack of correlation between temperature and D.O. and its presence between pH, D.O. and SSL may demonstrate a relationship with the discharges.

Turbidity was found to be negatively correlated to temperature at the northernmost four stations in the East Waterway. This may be the result of winter storm drain discharges and runoff from paved or filled areas into the East Waterway or seasonal discharge maxima from the Snohomish River. It is unlikely that the industrial discharges affected the turbidity. Turbidity varied with load at only one deep station (ECB203) and one beach station (ECB101). The beach station is located adjacent to a large stream located along the beach. The reason for the correlation at the deep station is not known.

The strike period from October 1978 through January 1979 provides a significant period of no discharge. PBI, D.O., and pH data from the strike period (the control) were compared with those obtained for a similar period during other years of the study (Table 7). The comparison was made for each station using a t-test for difference between two means of two groups of data whose variances are assumed to be unequal (Sokal and Rohlf, 1969). There were many zeros in the SSL data during the strike period. These skewed the data distribution excessively so that the standard deviation (s) exceeded the mean. In order to correct this apparently non-normal distribution, the data were transformed using log (Y+1). This also allowed the inclusion of zero values in the analysis.

At all stations, the averages for SSL during the no-discharge period were lower than similar periods when discharge was occurring. However, they did not prove to be significantly different from one another. Similarly, average D.O. and pH values were higher at all stations, but not statistically different. Dissolved oxygen and pH variation may have been influenced by factors other than discharge; physical factors (temperature, solar radiation), biological factors (primary productivity, respiration, decomposition, etc.) and non-paper industrial practices discussed earlier. In summary, common sense may suggest that a cause-and-effect relationship between the water quality variables and BOD loads exists, but this relationship is not proved statistically.

Improvements in water quality could not be shown by the available species diversity data at deep stations. Catches were greater and more consistent at beach seine stations. If one assumes that improving water quality should lead to a more diversified marine fauna (greater diversity), then this may be the

Table 7. A comparision of means for three water quality variables obtained during a period of industrial shutdown (no discharge) with means from a similar period when production occurred (discharge). Data were analyzed using a method in which sample variances are assumed to be unequal (Sokal and Rohlf, 1969).

Parameter	ECB101	ECB102	ECB103	ECB104	Overall Average Beach-Seine Sites
D.O. (mg/L)					
No discharge	8.7 + 1.4(3)	8.9 + 1.2(3)	9.2 + 1.1(3)	9.3 + 0.8(3)	9.0 + 1.0(12)
Discharge	7.8 + 2.2(22)	8.2 + 1.2(23)	8.8 + 1.2(23)	8.7 + 1.7(20)	8.4 + 2.0(87)
t's[1]	0.345	0.289	0.245	0.319	0.268
t'.05[2]	2.401	2.355	2.578	2.285	2.179
Conclusion	nsd[3]	nsd	nsd	nsd	nsd
pH (units)					
No discharge	7.7 + 0.2(3)	7.8 + 0.1(3)	7.9 + 0.0(3)	7.8 + 0.1(3)	7.8 + 0.1(12)
Discharge	7.4 + 0.3(21)	7.6 + 0.3(21)	7.6 + 0.3(22)	7.7 + 0.6(19)	7.6 + 0.4(83)
t's[1]	0.728	0.633	1.00	0.164	0.485
t'.05[2]	2.420	2.190	2.084	2.116	2.001
Conclusion	nsd	nsd	nsd	nsd	nsd
SSL (mg/L)					
No discharge	0.59 + 0.53(3)	0.85 + 0.13(3)	0.75 + 0.05(3)	0.67 + 0.58(3)	0.72 + 0.35(12)
Discharge	1.10 + 0.64(21)	1.00 + 0.49(22)	0.98 + 0.46(23)	0.95 + 0.48(20)	1.01 + 0.52(86)
t's[1]	0.613	0.294	0.497	0.372	0.469
t'.05[2]	2.530	1.946	2.083	2.739	1.712
Conclusion	nsd	nsd	nsd	nsd	nsd

	ECB201	ECB202	ECB203	ECB204	ECB205	Overall Average Deep-Seine Sites
D.O. (mg/L)						
No discharge	8.4 + 1.0(4)	8.2 + 1.0(4)	9.8 + 0.6(4)	7.5 + 0.4(4)	7.3 + 0.3(4)	7.8 + 0.8(20)
Discharge	8.0 + 2.3(23)	7.9 + 2.4(23)	7.6 + 2.7(23)	7.3 + 2.7(21)	6.9 + 2.8(22)	7.6 + 2.6(112)
t's[1]	0.159	0.115	0.748	0.073	0.147	0.073
t'.05[2]	2.196	2.773	2.118	2.095	2.099	1.992
Conclusion	nsd	nsd	nsd	nsd	nsd	nsd
pH (units)						
No discharge	7.7 + 0.2(4)	7.8 + 0.1(4)	7.8 + 0.2(4)	7.7 + 0.2(4)	7.6 0.1(4)	7.7 + 0.2(20)
Discharge	7.4 + 0.4(22)	7.4 + 0.4(22)	7.4 + 0.3(22)	7.2 + 0.5(21)	7.4 + 0.4(22)	7.3 + 0.4(109)
t's[1]	0.671	0.971	1.111	0.928	0.472	0.895
t'.05[2]	2.222	2.126	2.300	2.176	2.163	1.999
Conclusion	nsd	nsd	nsd	nsd	nsd	nsd
SSL (mg/L)						
No discharge	0.64 + 0.40(4)	0.20 + 0.39(4)	0.59 + 0.39(4)	0.62 + 0.43(4)	0.76 + 0.05(4)	0.56 + 0.38(20)
Discharge	1.08 + 0.67(23)	1.15 + 0.40(23)	1.29 + 0.52(23)	1.47 + 0.38(21)	1.27 + 0.53(23)	1.25 + 0.52(113)
t's[1]	0.564	1.702	1.078	1.466	0.962	1.070
t'.05[2]	2.255	2.413	2.325	2.463	2.074	2.018
Conclusion	nsd	nsd	nsd	nsd	nsd	nsd

[1]t's: estimated value of t based on weighted averages and differing degrees of freedom in two samples assumed to have unequal variances.

[2]t'.05: critical value of t's at alpha = 0.05.

[3]nsd: no significant difference.

case at beach station ECB103 only. This is the only station at which species diversity significantly increased over time (Table 5) and increasing diversity correlates with load reductions (Table 6).

CONCLUSIONS

There are several indicators of water quality improvement in Port Gardner during the ECOBAM study. Trend analysis shows that PBI (the variable most closely associated with pulp and paper waste discharges) significantly declined over the years at all stations. There was significant increase in pH at all stations, and D.O. increased at four of five stations in the East Waterway which receives wastes directly from the nearshore discharge. Other variables showed little improvement.

Correlation analysis revealed significant association of loads with PBI (positive) and pH (negative) at all stations. Association of pH with discharge from the Snohomish River (a major source of natural variation) was not significant.

It cannot be proven conclusively that waste load reductions from the two pulping industries resulted in water quality improvement. However, trend and correlation analyses provide evidence that such a cause-and-effect relationship may exist. Although PBI, D.O., and pH were significantly correlated (PBI, pH, and loads likewise), D.O. was not significantly associated with loads at any station due to interacting environmental factors.

ACKNOWLEDGMENTS

Acknowledgments are due to several Ecology workers associated with ECOBAM over the years. Roland Pine developed the initial design for the physical, chemical, and biological sampling program. Allen Moore and Darrel Anderson carried out the field sampling during the early years. Dale Clark carried out later sampling. Advice and suggestions have been provided by Murl Miller and Tim Bechtel of the Scott Paper Company. Mr. Miller and Robert Anderson of Weyerhaeuser Company, Inc. provided access to or supplied waste load data. Assistance in computer analysis and graphing was provided by Robert James and Shirley Prescott of the Water Quality Investigations Section of Ecology, and Ray Peterson of the Environmental Services Division, Environmental Protection Agency, Region 10. John Bernhardt reviewed the manuscript, and Carol Perez provided many suggestions and typing skills. John Milhollin, Ecology cartographer, provided the figures.

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